# Humanitarian mine action - Test and evaluation - Part 2: Soil characterization for metal detector and ground penetrating radar

# CEN WORKSHOP AGREEMENT

# CWA 14747-2

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## Humanitarian mine action - Test and evaluation - Part 2: Soil characterization for metal detector and ground penetrating radar performance

This CEN Workshop Agreement has been drafted and approved by a Workshop of representatives of interested parties, the constitution of which is indicated in the foreword of this Workshop Agreement.

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# Contents

# Foreword

CWA 14747 consists of the following parts, under the general title **Mine Action — Test and evaluation**:

- Part 1: Metal detectors (CWA 14747-1)
- Part 2: Soil characterisation for metal detector and ground penetrating radar performance (CWA 14747-2)

The first part of CEN Workshop Agreement (CWA) 14747 was approved by the CEN Workshop 7 on 6 May 2003 [4]. The Chairmanship and Technical Secretariat were provided by the European Commission - Joint Research Centre (JRC) at Ispra (Italy). The professional standardisation support was provided by UNI (Italian CEN Member).

This second part of the CEN Workshop Agreement was approved by representatives of interested parties in the reactivated CEN Workshop 7 on 29 May 2008. The Chairmanship and Technical Secretariat were provided by the Royal Military School (RMS) at Brussels (Belgium). The professional standardisation support was provided by AFNOR (French CEN Member). The endorsement round for this part of CWA 14747 was started on 15 June 2008 and was successfully closed on 4 September 2008.

The following international organisations or programme have given a support to the project:

- International Test and Evaluation Program for Humanitarian Demining (ITEP),
- United Nations Mine Action Service (UNMAS), and
- Geneva International Centre for Humanitarian Demining (GICHD).

The development of this part of CWA 14747 has benefited from a financial contribution of the European Commission and EFTA allocated in the context of the European Commission Mandate M/306.

The individuals and organizations that supported the technical consensus represented by the CEN Workshop Agreement were drawn from the following economic sectors: metal detector and ground penetrating radar manufacturers, R&D institutions with experience of soils, metal detector and ground penetrating radar development and testing, demining engineers and demining Non Governmental Organisations using metal detectors. Participants came from eleven different countries as well as from the United Nations.

It is to be noted that this part of CWA 14747 represents the current state of the art. The contents, however, could be later reviewed in order to input more refined information.

Comments or suggestions from the users of the CEN Workshop Agreement are welcome and should be addressed to the CEN Management Centre.

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# Introduction

Following a mandate issued by the European Commission, CEN created a Working Group of the CEN Technical Board, BT/WG 126 in January 2001, to ensure coordination and generate specific standardisation initiatives useful for humanitarian mine action.

Among the CEN Workshops created within this field, CEN Workshop 7 was dedicated to the test and evaluation of metal detectors. It eventually produced CWA 14747-1.

CWA 14747-1 has been extensively used and tested in many activities performed by members of the International Test and Evaluation Program for Humanitarian Demining (ITEP). The results of these tests are public. CWA 14747-1 is referenced in the International Mine Action Standard IMAS 3.40.

The experience gathered when using CWA 14747-1 made it clear that being able to characterise the soils with regard to their influences on the performance of metal detectors would be very valuable.

Such a soil characterisation would have several significant advantages:

- Field operators would be able to have an indication about how difficult a soil would be for their detectors;

- People testing and evaluating mine detectors would be able to better take into account the effects of soils when designing the trials and analysing the test results.

Moreover several new dual detectors combining metal detectors with ground penetrating radars (GPR) have been made available recently [10]. A ground penetrating radar is an instrument designed to detect contrasts in the electromagnetic properties that can occur between mines and soil. Since ground penetrating radar performance is affected by soil characteristics in different ways from metal detector performance, being able to characterise soils also for ground penetrating radar purposes would be useful in order to help choosing and documenting the soils used in tests of dual sensors and later the selection of dual sensors by future customers.

This part of CWA 14747 has been prepared by the reactivated CEN Workshop 7, "Humanitarian Mine Action - Test and Evaluation" (CW07). CW07 was re-established with the objective of developing and agreeing on protocols for characterising the effects of soils on the performance of metal detectors and dual sensors combining metal detectors and ground penetrating radars.

This part of CWA 14747 has been prepared under a mandate given to CEN by the European Commission. Support has also been given by CEN BT/WG 126, by the United Nations Mine Action Service (UNMAS) and by the Geneva International Centre for Humanitarian Demining (GICHD). Close co-operation has been maintained with GICHD and UNMAS, with the aim of including it in the IMAS system at a later stage.

CW07 was re-launched on 15 November 2006 at CEN Management Centre (CMC) in Brussels when the Business Plan was approved. The Workshop process has been chaired by the Royal Military School (RMS). Plenary meetings of the Workshop took place at the Royal Military School in Brussels or CMC in May and October 2007 and January and May 2008.

This document has been written following as much as possible the rules given in *CEN/CENELEC Internal Regulations, Part 3: Rules for the structure and drafting of CEN/CENELEC Publications.* This includes the following:

— The main division of the document is called a clause, not a chapter, and it is referred to with its number. For instance, the clause “Symbols and abbreviations” is referred to in the document as 4.

— Bibliographical references are referred to with their numbers between square brackets. For instance, *CEN/CENELEC Internal Regulations, Part 3: Rules for the structure and drafting of CEN/CENELEC Publications* is referred to in the document as [5].

— Commas are used as decimal signs.

# 1 Scope

This CEN Workshop Agreement provides **mine action programmes, demining companies and field operators** with:

— simple procedures to asses the effects of soils on the performance of metal detectors and dual sensors (see 5) and

— clues to recognise soils that may create difficulties to metal detectors (see 5.6) and dual sensors (see 5.7).

It also provides **people designing tests to evaluate metal detectors or dual sensors** with:

— a list of soil properties to record that can affect the performance of these detectors (see 6.2),

— procedures to determine these properties (see Annex B),

— relative soil comparison rules to compare and choose soils for testing (see 6.4 and 6.5), and

— soil classifications based on the effects on metal detector performance (see 6.3); no such classification is currently available for dual sensors.

NOTE A CEN Workshop Agreement is an agreement developed by a Workshop, which reflects the consensus of the identified individuals and organizations responsible for its contents [5]. Therefore this document is *not* a standard, but an agreement reflecting the best practice and the state of knowledge at the time of its writing.

This part of CWA 14747 complements the first part — which provides guidelines, principles and procedures for the testing and evaluation of metal detectors — by adding guidelines to characterise soils for both metal detectors and ground penetrating radars.

First, methods to **characterise soils during field operations** using metal detectors or dual sensors are given in 5. These methods do not need additional instruments to measure soil properties.

Then a description of how **to characterise soils when testing and evaluating** metal detectors or dual sensors is given in 6. A list of useful soil properties is provided and methods to measure or compute them can be found in Annex B.

Table 1 lists the most important clauses:

**Table 1 — Information provided in the document**

| Intended readers | Information provided | Clauses |
|---|---|---|
| Mine action programmes, demining companies and field operators | Procedures to asses the effects of soils on metal detectors | 5.2 (Fixed-depth detection test)<br>5.3 (Equivalent detection depth test)<br>5.4 (Ground reference height) |
| | Procedures to asses the effects of soils on the performance of dual sensor | 5.5 (Fixed-depth detection test) |
| | Clues to recognise soils that may create difficulties to metal detectors | 5.6 (Clues to recognise difficult soils for metal detectors) |
| | Clues to recognise soils that may create difficulties to dual sensors | 5.7 (Clues to recognise difficult soils for dual sensors) |
| People designing tests to evaluate metal detectors or dual sensors | List of soil properties that can affect the performance of these detectors | 6.2 (List of soil properties) |
| | Procedures to determine above soil properties | Annex B (How to determine soil properties) |
| | Soil classification based on the effects on metal detector performance | 6.3.2 (based on ground reference height)<br>6.3.3 (based on low frequency magnetic susceptibility)<br>6.3.4 (based on frequency variation of magnetic susceptibility) |
| | Relative soil comparison rules | 6.4 (for metal detectors)<br>6.5 (for ground penetrating radars) |

This CEN Workshop Agreement applies to all types of hand-held metal detectors, ground penetrating radars and dual sensors combining metal detectors and ground penetrating radars for use in humanitarian demining. The Agreement is intended to be used for "commercial off-the-shelf" (COTS) detectors with a clear procedure to detect a mine, but some tests specified within it could be applied to instruments under development.

## 2 Normative References

This part of CWA 14747 incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this part of CWA 14747 only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

IMAS 04.10, Glossary of mine action terms and abbreviations, Edition 2, 01 January 2003, UNMAS, New York, available at http://www.mineactionstandards.org/imas.htm

International Electrotechnical Vocabulary, available at http://www.electropedia.org/, 2007

Metal detector handbook for humanitarian demining, Guelle D, Smith A, Lewis A, Bloodworth T, http://www.itep.ws/pdf/metal_detector_handbook.pdf

# 3 Terms and definitions

For the purposes of this document, the terms and definitions given in CWA 14747-1 and the following apply.

**3.1**
**Alarm indication**
A signal to warn of the detection of an object; the indication can be visual and/or auditory. A positive alarm indication is repeatable under the same conditions and is not intermittent.

NOTE This definition is adapted from CWA 14747-1, 3.1.

**3.2**
**Attenuation**
Progressive reduction in the amplitude of an electromagnetic signal due to interaction (absorption and scattering) with the material medium through which it is transmitted

**3.3**
**Conductivity (effective electrical)**
See effective electrical conductivity

**3.4**
**Dual sensor**
Integrated sensor system combining a metal detector and a ground penetrating radar

**3.5**
**Effective electrical conductivity**
Parameter quantifying a material's ability to carry (or conduct) an electrical current; 'Effective' means that it includes partly the effect of electric permittivity. It is expressed in siemens per metre ($Sm^{-1}$)

**3.6**
**Effective relative electric permittivity**
Electric permittivity quantifies a material's tendency to be polarised by an applied electric field. 'Relative' means that it is normalised by the free-space electric permittivity and 'effective' means that it includes partly the effect of conductivity and is what is effectively measured. It is a dimensionless parameter in the SI system

**3.7**
**False alarm**
Alarm indication that is not produced by a true test target or an unintentional metal fragment

**3.8**
**False alarm rate**
Number of false alarms counted on an area divided by the size of that area, or the average number of false alarms per square metre. The area is calculated as the area of the test lane minus the area of all detection halos. Measurement unit: $m^{-2}$.

**3.9**
**False test object**
Object not intended to be detected, or a soil perturbation, introduced intentionally in the soil of a test site and that may generate an alarm indication. It is an item that can be representative of a non-mine object that is expected to generate an alarm indication for the detector

**3.10**
**Magnetic susceptibility**
Parameter quantifying a material's tendency to be magnetised by an applied magnetic field; It is a dimensionless parameter in the SI system

**3.11**
**Measuring instrument**
Instrument used to measure a soil property

**3.12**
**Permittivity (Effective relative electric)**
See effective relative electric permittivity

**3.13**
**Probability of detection**
Probability of detecting a true test target, which can be estimated as the ratio of the number of detected true test targets to the total number of opportunities to detect a true test target; the probability of detection depends on many parameters such as the operator, the metal detector or dual sensor, the types of true test targets used and the soil

**3.14**
**Reflection**
The physical process through which a propagating radar pulse incident on an interface separating soils, air, mine or other media having contrasting electromagnetic parameters is partially re-radiated back into the medium of incidence and ultimately detected at the receiving antenna.

**3.15**
**Scattering**
Process by which the energy carried by radar pulse or other electromagnetic wave field incident upon a localized heterogeneity (i.e. cobble, mine, etc.), called a scatterer, or an irregular interface (i.e. rough or vegetated ground surface) is re-radiated to some extent in all directions. The angle-distributed pattern of scattered energy depends on the geometry of the scatterer, the angle of incidence, the spectral content of the incident pulse and the contrast between electromagnetic properties of the scatterer and host media.

**3.16**
**Susceptibility (magnetic)**
See magnetic susceptibility

**3.17**
**Test object**
Object deliberately buried for testing. There are two kinds of test objects: true test targets and false test objects.

**3.18**
**True test target**
Object that is introduced intentionally in the soil of a test site in order to test the detection performance of a detector; It is an item that can be chosen to be representative of a mine or mine component, or it can be a simple object to be used in sensitivity measurement

**3.19**
**Unintentional metal fragment**
Metal fragment present in a soil without having been introduced for a test

# 4 Symbols and abbreviations

## 4.1 Organisations and programs

**4.1.1**
**AFNOR**
Association française de normalisation, French member of CEN

**4.1.2**
**CEN**
European Committee for Standardization – Comité européen de normalisation – Europäisches Komitee für Normung

**4.1.3**
**GICHD**
Geneva International Centre for Humanitarian Demining

**4.1.4**
**ITEP**
International Test and Evaluation Program for Humanitarian Demining

**4.1.5**
**RMS**
Royal Military School

**4.1.6**
**UNMAS**
United Nations Mine Action Service

## 4.2 Others

**4.2.1**
**CWA**
CEN Workshop Agreement; a CWA is a document developed by a Workshop, which reflects the consensus of identified individuals and organizations responsible for its content.

Source: *CEN/CENELEC Internal Regulations, Part 3: Rules for the structure and drafting of CEN/CENELEC Publications*, 3.14.1, [5].

**4.2.2**
**GPR**
Ground penetrating radar

**4.2.3**
**IMAS**
International Mine Action Standard

# 5 Soil characterisation during field operations

## 5.1 General

**This clause is relevant to mine action programmes, demining companies and field operators. It explains how to characterise the effects of soils on metal detectors and dual sensors during field operations.**

Two methods to determine the effect of soil on the detection performance of metal detectors are described: one in 5.2 where the true test targets are buried and one in 5.3, where the true test targets are in air, that is faster, more precise but may not be adequate for all soils. The use of the ground reference height, which gives a rough estimate of how difficult a soil is, is described in 5.4.

For field operations using dual sensors a method to determine the detection capability for buried true test targets at fixed depths in a given soil is described in 5.5.

For a better understanding of how soils affect the performance of metal detectors and ground penetrating radars, and a definition of soil classes for metal detectors, see Annex A.

Since soil properties may vary from one location to the next, it is important to repeat these tests when and if the soil varies. Indications that soil properties vary include:

— Dissimilar terrain or slope position,

— Dissimilar soil colour on the surface,

— Dissimilar texture,

— Dissimilar stone content and dissimilar amount of rock outcrops,

— Dissimilar land use and vegetation.

NOTE When there is a slope; soil properties tend to vary more in the direction of the slope.

## 5.2 Metal detectors: fixed-depth detection test

The objective of this test is to characterise the effects of the soil by determining the detection capability of the metal detector for buried true test targets at fixed depths in a given soil. The detection capability is therefore expressed simply as true test target detected or not detected at the test depth. The test is an open test i.e. the position of the true test target is marked on the surface above the true test targets with non-metallic markers (*e.g.* plastic discs).

The test is described in CWA 14747-1, 8.4.

NOTE This test assumes that the detection of a true test target by a metal detector is deterministic that is, for any test with a given true test target at a given depth in a given soil with a given metal detector, the result will always be the same: either the true test target will always be detected or always be missed. With some soils, however, a given true test target at a given depth can sometimes be detected and sometimes missed by the same metal detector, or a true test target can be detected at some depth and missed at a smaller depth. If this happens, the test described in Annex D, which takes into account the non-deterministic character of the detection, should be used instead.

## 5.3 Metal detectors: equivalent detection depth test

### 5.3.1 Principle

The objective of this test is to characterise the effects of the soil by estimating the maximum detection depth of a given true test target without having to bury it. The detection capability is expressed as an equivalent detection depth.

The test is based on the assumption that the response of an in-air true test target above the soil is the same as the response of a buried true test target, provided the detector is swept at the same height above the ground, as seen in Figure 1. This assumption is expected to be valid for most soils and most detectors. See D.3 for more details and a test to confirm this assumption for a given soil and detector.

This test is simpler than fixed-depth detection test because there is no need to bury true test targets. It also leads to greater precision, as it is easier to use smaller steps for the distance between the true test target and the sensor head. It nevertheless requires the above assumption to be valid.

### 5.3.2 Equipment and test area

The test area should be representative of the area where the metal detector will be actually used. It can be a cleared area or should be similar to a cleared area and free of vegetation and metal fragments.

Any true test target of interest can be used for the test, but the measurement is dependent on the true test target used. Therefore to be able to compare results demining programmes can benefit from standardising their measurements by choosing a reference true test target.

### 5.3.3 Procedure

The detector shall be set up as normal to the maximum sensitivity for the soil so that it does not give any alarm indication when swept at normal height according to the user manual and local standard operational procedures. If this fails the soil cannot be compensated for this detector and the test is stopped.

If the detector can be operated in several modes, modes used in actual operations shall be tested. Other modes may also be tested if appropriate.

The true test target shall be placed at a fixed height above the soil. The detector shall be swept over the ground to determine if the true test target is detected. The true test target is considered detected if a consistent alarm indication is obtained for at least five (5) consecutive sweeps. Care must be taken to ensure that the true test target remains fixed and the sweep height is kept constant during the sweeping. A non-metallic jig may be useful for this.

The initial height of the true test target above the soil shall be chosen so that the true test target is detected. The height of the true test target above the ground shall be increased in increments (of 10 mm max.) until detection stops. The previous height — the last one at which there is detection — is used to compute the equivalent detection depth according to Figure 1.

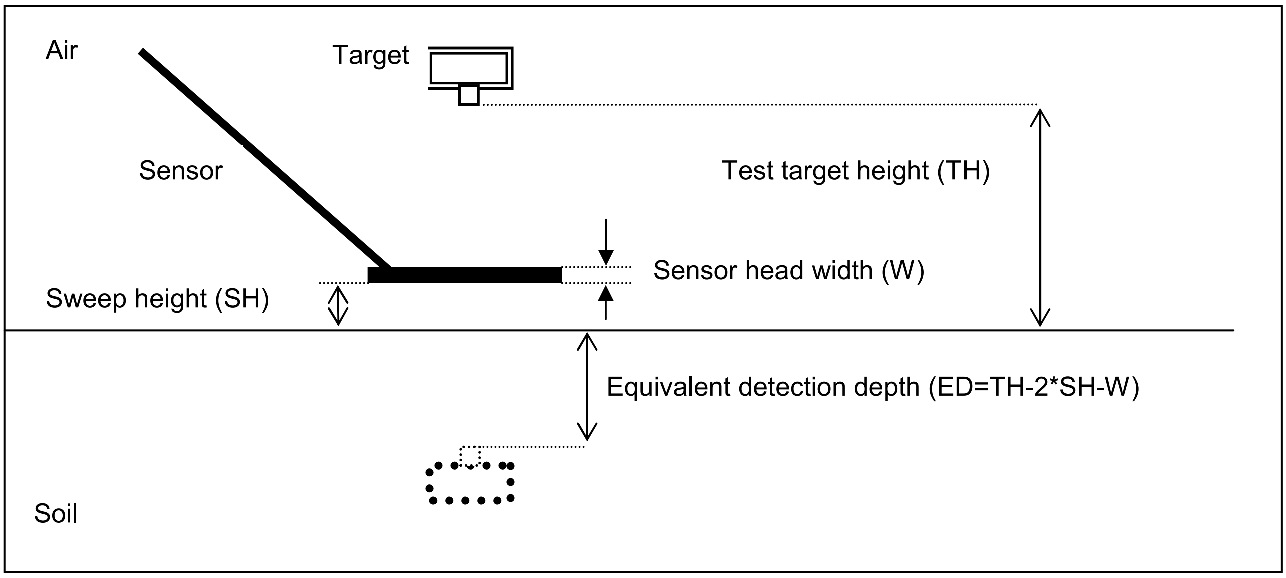


**Figure 1— Geometry for soil influence on detection distance test and definition of the equivalent detection depth**

An estimate shall be made of the accuracy to which the maximum detection height can be measured. This estimate shall include the uncertainty arising from judging the detection limit and from making the measurement. This accuracy estimate shall be recorded.

#### 5.3.4 Test results and reporting

The equivalent detection depth, the accuracy, the sweep height, the make, model and setting of the metal detector and the true test targets used shall be recorded.

### 5.4 Metal detectors: ground reference height

#### 5.4.1 Principle

The ground reference height expresses the level of influence of the soil on the metal detector. The greater it is, the greater the influence. Ground reference height can be seen as an empirical measurement of how ‘noisy’ or ‘uncooperative’ a soil is.

This method is the easiest to use during field operations as it is simple and does not require the purchase of a specific measuring instrument since it uses a commercial, off-the-shelf metal detector.

NOTE Demining organisations can use the ground reference height to plan the use of their metal detectors.

#### 5.4.2 Equipment and test area

Metal detectors suitable for measuring the ground reference height shall have continuous sensitivity adjustment. Metal detectors that can work in static mode and without ground compensation should be preferred.

NOTE Both dynamic mode and ground compensation are designed to reduce the soil response, leading to a decreased sensitivity to the soil response and therefore the ground reference height is reduced and measured with less accuracy. Furthermore, the measurement is easier and has a higher accuracy in static mode because no movement of the detector head is required.

The measurement is highly dependent on the detector used. To be able to compare results demining programmes can benefit from standardising their measurements by choosing a reference metal detector that is easily available and fulfils the above requirement.

People interested in measuring ground reference heights that can be compared with other soils might want to choose the metal detector model used in previous measurement campaigns, such as [11], [12], [12] and [17].

Setting up the metal detector for ground reference height measurement is important in order to be able to compare results. The setup of the metal detector is done as follows:

- A 10-mm diameter chrome steel ball (10mm Ø 100 Cr6) is placed 140 mm away from the sensor head in air. The true test target and sensor head are aligned according to CWA 14747-1, 6.3.2.
- The sensitivity is then increased to a point where it gives an alarm indication. If the detector works in dynamic mode the sensor head must be swept. The detection shall be determined by following CWA 14747-1, 5.5.

The test area should be representative of the area where the metal detector will be actually used. It should be reasonably flat, homogeneous, with little vegetation and contain as few metal fragments as possible.

This should be repeated several times for confirmation and in a number of locations if appropriate. See B.2.4 for a procedure to measure the spatial variability.

#### 5.4.3 Procedure

The ground reference height is defined as the distance between the soil surface and the detector when the detector gives an alarm indication as it is brought closer to the soil surface from above.

The distance at which the detector starts to give a definite indication alarm during a ground reference height measurement is somewhat subjective but if a point is chosen in the same way as during the setup procedure, the results should be reproducible.

#### 5.4.4 Test results and reporting

The ground reference height measurements shall be recorded. The make and model of the metal detectors used shall be recorded too.

#### 5.4.5 Example: Values for a specific make and model of metal detector

Table 2 provides ground reference height values, measured by the Schiebel AN19 Mod 7, for the four soil classes defined in A.2. The effect of a soil on a given metal detector depends on the specific detector design. Therefore these values are only indicative.

**Table 2 — Indicative values for ground reference height as measured by Schiebel AN 19 Mod 7 metal detectors, from [3]; soil classes are defined in A.2.**

| Soil effect class (defined in A.2) | Ground Reference Height cm |
|---|---|
| | (Measuring instrument: Schiebel AN19 Mod 7) |
| **Neutral** | Below 1 |
| **Moderate** | 1 to 10 |
| **Severe** | 10 to 20 |
| **Very severe** | Above 20 |
| NOTE These values are only indicative because the effect of a soil on a metal detector used in mine clearance depends on this metal detector, and the measured values of ground reference height depend on the measuring instrument, here the Schiebel AN19 Mod 7. | |

NOTE The Schiebel AN 19 Mod 7 can be set up as described in 5.4.2 or alternately by using the Schiebel test piece at a distance of 100 mm. The setup procedure should be reported.

Demining organisations may benefit from building a similar table for the detector chosen as reference. This is possible if results of fixed-depth detection test and equivalent detection depth test are available for various soils. For this, definitions of soil classes are given in Table A.1.

### 5.5 Dual sensors: fixed-depth detection test

#### 5.5.1 Principle

The objective of this test is to determine the detection capability of the dual sensors for buried true test targets at fixed depths in a given soil. The detection capability is therefore expressed simply as true test target detected or not detected at the test depth. The test is an open test i.e. the position of the true test target is marked on the surface above the true test targets with non-metallic markers (*e.g.* plastic discs). It is a version of 5.2 modified for dual sensors.

NOTE This test assumes that the detection of a true test target by a dual sensor is deterministic that is, that for any test with a given mine at a given depth with a given dual sensor, the result will always be the same: either the mine will always be detected or always be missed. With some soils, however, a given mine at a given depth can sometimes be detected and sometimes missed by the same dual sensor, or a mine can be detected at some depth and missed at a smaller depth. If this happens, the test described in Annex E should be used instead.

#### 5.5.2 Equipment and test area

The test area should be representative of the area where the dual sensor will be actually used. It should be reasonably flat, homogeneous, with little vegetation and contain as few metal fragments, few roots, rocks or cracks as possible. Additional requirements are defined in CWA 14747-1, 8.1.2.

The true test targets to be used for this test are:

— true test targets specially designed to emulate a mine for metal detectors and ground penetrating radars,

— any other specific true test target of interest.

Simulating a mine for dual sensors can be done by filling an ABS or PVC plastic casing, the size and shape of the mine, with an explosive simulant, such as beeswax, microcrystalline wax or silicon, and keeping an air-gap inside. A fuse should be placed at the proper location inside the casing. The casing should be closed hermetically to prevent any water to penetrate.

#### 5.5.3 Procedure

The true test targets should be buried preferably 1 m, and at least 50 cm, apart from each other at a depth ranging from 0 mm (flush) to at least 150 mm by steps of at most 50 mm, and preferably 30 mm. They should be buried at locations where the dual sensor does not give any alarm indication.

Measurements shall be performed only after the soil has returned as much as possible to the state of soil at a mine location in real situation. This time is difficult to estimate but a conservative approach is to wait until the ground penetrating radar cannot detect the soil perturbation anymore. This can be done by using a control location as follows: Disturb the soil on the control location as would occur if a true test target were buried at the maximum depth but without actually burying it. The control location can then be checked regularly with the ground penetrating radar and measurements on the buried true test targets shall only start once there is no alarm indication on the control location.

NOTE 1 When using a dual sensor that does not provide separate alarm indications for the metal detector and the ground penetrating radar, a small metal fragment that can easily be detected by a metal detector should be buried in the control location at the bottom of the hole.

NOTE 2 For some soils, the soil settling time may be prohibitively long and another reasonable rest time should be chosen.

Water may be used to reduce the time before measurements can start. If water and a control location are used, water shall be used identically on the true test target locations and the control location. Sprinkling should be done homogenously and the irrigated area should be large enough to cover the footprint of the dual sensor.

The detector shall be set up according to the manufacturer's procedure. If applicable, the settings used shall be recorded.

The detection should be repeated at least at two, and preferably three, different locations with similar soil conditions.

When not conflicting with what has been stated above, procedure described in CWA 14747-1,8.4.3 shall be followed.

#### 5.5.4 Test results and reporting

The result of detection for each true test target shall be recorded together with the type of true test targets and burial depths.

### 5.6 Clues to recognise difficult soils for metal detectors

#### 5.6.1 Introduction

It is recommended that Ground Reference Height measurements be made to determine the likely soil effect on metal detectors. See 5.4.

In addition clues can be given to recognise two types of soils that may affect metal detectors: magnetic soils and saline soils. The use of metal detectors with soil compensation may mitigate the soil effect but the sensitivity of the detector may then be reduced.

#### 5.6.2 Recognising highly magnetic soils

There are no specific diagnostic features for recognising magnetic soils in the field. Magnetic soils often have a reddish colour, but not all reddish soils are magnetic.

Soils with a high proportion of magnetic particles can be recognised with the following test.

**Test: Recognising highly magnetic soils**

Take a soil sample; let it dry; turn it into grains as fine as possible; put them on a sheet of paper; sweep the magnet below the paper. If some soil particles are moving the soil is highly magnetic.

Soils that are identified as highly magnetic by this test may have strong negative effects on the performance of metal detectors (increased numbers of false alarms and/or reduced detection depth). However soils that do not react to the test may still have these negative effects.

NOTE 1 This test is not very sensitive. It recognises only highly magnetic soils.

NOTE 2 This test is only sensitive to the intensity of the magnetic properties of the soil. It may not be adequate for pulse induction metal detectors, which are sensitive to the variation of the soil magnetic properties with frequency.

### 5.6.3 Recognising saline soils in the field

Soils with high salt content can have a high effective electrical conductivity **when wet** and in some cases may negatively affect metal detectors. These soils can be found inland and on the coasts. The following features can be used to recognise these saline soils.

- Coastal beach environment
- White salt crusts present on the soil surface only during dry periods
- The salt crust surface is often 'puffy' when dry
- Salt-tolerant vegetation present.

NOTE When dry, these soils have usually no effect on metal detector performance.

## 5.7 Clues to recognise difficult soils for dual sensors

A dual sensor combines a metal detector and a ground penetrating radar. Therefore 5.6 applies.

In addition difficult soils for ground penetrating radar include:

- soil with surface roughness,
- wet soils and especially when there are small-scale spatial variations in soil water content, and
- soils with inhomogeneities, roots, stones, voids, etc.

With such soils dual sensors may experience difficulties.

# 6 Soil characterisation during test and evaluation

## 6.1 General

**This clause is relevant to people designing tests to evaluate metal detectors or dual sensors. It provides a list of soil properties that affect the performance of such detectors and some guidelines to characterise soils.**

A list of soil properties that have an effect on performance is given in 6.2. Methods to measure or compute them are described in Annex B.

Although it is not currently possible to link accurately these properties to performance, some indicative classifications of soils based on some of these properties are given in 6.3 for metal detectors. At the current state of knowledge it is not possible to provide even indicative classifications for ground penetrating radars.

It is, however, possible to describe in general how performance is expected to vary when some soil properties change. This is covered in 6.4 for metal detectors and in 6.5 for ground penetrating radars.

## 6.2 List of soil properties

Table 3 shows which soil properties to measure in order to characterise the soil during a test and evaluation of metal detectors or dual sensors.

**Table 3 — Soil properties to measure in order to characterise the soil during a trial. The symbol ● refers to essential soil properties that shall be measured and the symbol ○ to desirable soil properties that should be measured.**

| Clause | Soil properties | Spatial variability (see B.2.4) | Metal detector | Ground penetrating radar |
|---|---|---|---|---|
| B.3 | Low frequency magnetic susceptibility | ● | ● | |
| B.3 | Magnetic susceptibilities at two frequencies | ● | ● | |
| 5.4 | Ground reference height | ○ | ○ | |
| B.4 | Effective relative permittivity | ● | | ● |
| B.5 | Effective electrical conductivity | ● | ○ | ● |
| B.6 | Attenuation coefficient[a] | ○ | | ○ |
| B.7 | Characteristic impedance[a] | ○ | | ○ |
| B.8 | Electric object size[a] | | | ○ |
| B.9 | Surface roughness | ○ | ○ | ○ |
| B.10 | Soil water content | ○ | | ○ |
| B.11 | Weather conditions | | ○ | ○ |
| B.12 | Soil texture | ○ | | ○ |
| B.13 | Vegetation | ○ | | ○ |
| B.14 | Roots | ○ | | ○ |
| B.15 | Rocks | ○ | ○ | ○ |
| B.16 | Surface cracks | ○ | | ○ |

NOTE 1 Measuring magnetic susceptibility at two frequencies is necessary for pulse induction metal detectors and possibly for most continuous wave metal detectors.

NOTE 2 For metal detectors surface roughness and spatial variability are important only when the soil generates a significant response.

[a] Property not directly measured but derived from effective permittivity and effective electrical conductivity.

NOTE Voids present in the ground have a great impact on ground penetrating radar performance, but no method to measure them is available.

## 6.3 Soil classifications for metal detectors

### 6.3.1 General

Three indicative soil classifications for metal detectors are given, one based on the ground reference height, one based on magnetic susceptibility and one based on frequency variation of magnetic susceptibility. These classifications are indicative only because they take into account dominant factors influencing metal detector performance but not all of them.

Table 4 summarises the advantages and disadvantages of each method and their recommended use.

**Table 4 — Advantages and disadvantages of the soil classification methods**

| Soil classification based on… | Advantages | Disadvantages | Recommendation |
|---|---|---|---|
| … ground reference height (see 6.3.2) | Does not require any specific measuring instrument.<br>Can be used to classify magnetic or electrically conductive soils | Classes depend on the metal detector used to make the measurements | For fast and simple soil classification |
| … low frequency magnetic susceptibility (see 6.3.3) | Does not depend on a given metal detector. | Requires a measuring instrument.<br>Does not take into account the frequency variation of magnetic susceptibility to which most metal detectors seem to be sensitive. | May be relevant only for continuous wave metal detectors using a single frequency. |
| … frequency variation of magnetic susceptibility (see 6.3.4) | Does not depend on a given metal detector. | Requires a measuring instrument<br>May require laboratory measurements. | May be relevant for pulsed induction metal detectors and most continuous wave metal detection |

### 6.3.2 Soil classification based on ground reference height

The indicative soil classification based on ground reference height is given in Table 2.

### 6.3.3 Soil classification based on low frequency magnetic susceptibility

Table 5 provides values for magnetic susceptibility that are expected for the four soil effects. It should be noted that the effect of a soil on a given metal detector depends on the specific detector design and the exact values of susceptibility depend on the measuring instrument used (frequencies used, volume of soil investigated). Therefore the values are only indicative.

**Table 5 — Indicative values of magnetic susceptibility that can be expected for soil effects for single frequency continuous wave metal detectors (From CWA 14747-1, A3)**

| Soil effect class (Defined in A.2) | Indicative values of magnetic susceptibility $10^{-5}$ SI |
|---|---|
| **Neutral** | Below 50 |
| **Moderate** | 50 to 500 |
| **Severe** | 500 to 2 000 |
| **Very severe** | Above 2 000 |
| NOTE These values are indicative only because the effect of a soil on a metal detector depends on the metal detector, and the measured values of susceptibility depend on the measuring instrument. | |

NOTE How to measure low frequency magnetic susceptibility is described in B.3.

### 6.3.4 Soil classification based on the frequency variation of magnetic susceptibility

Table 6 provides indicative values for frequency variation of magnetic susceptibility that are expected for the four soil effects. It should be noted that the effect of a soil on a given metal detector depends on the specific detector design and the exact values of susceptibility depend on the measuring instrument used (frequencies used, volume of soil investigated).

**Table 6 — Indicative values of frequency variation of magnetic susceptibility that can be expected for soil effects for pulsed induction and most continuous wave metal detectors (From [1])**

| Soil effect class (Defined in A.2) | Indicative values of frequency variation of magnetic susceptibility (465 Hz and 4 650 Hz) $10^{-5}$ SI |
|---|---|
| **Neutral** | Below 5 |
| **Moderate** | 5 to 15 |
| **Severe** | 15 to 25 |
| **Very severe** | Above 25 |
| NOTE These values are indicative only because the effect of a soil on a metal detector depends on the metal detector, and the measured values of susceptibility depend on the measuring instrument. | |

NOTE How to measure frequency variation of magnetic susceptibility is described in B.3.

## 6.4 Relative soil comparison rules for metal detectors

The following rules describe qualitatively how some soil properties influence the performance of metal detectors. This is expected to be useful to select soils to build test lanes.

Table 7 describes the effect of an increase of some soil properties on the detector performance. As the effect may be different for pulsed induction and continuous wave detectors, a separate column is used for each detector technology. In each case, the clause in which the procedure to measure the soil property is described is indicated in the last column.

**Table 7 — Summary of the expected impact of an increase of soil property values on metal detector performance**

| Soil property | Effect on single frequency continuous wave metal detectors | Effect on pulsed induction metal detectors | Clause |
|---|---|---|---|
| **Low frequency magnetic susceptibility** | Strong decrease | Little or no decrease | B.3 |
| **Frequency variation of magnetic susceptibility** | No effect | Strong decrease | B.3 |
| **Spatial variance of low frequency magnetic susceptibility** | Strong decrease if the low frequency magnetic susceptibility is high enough to affect the detector | Little or no decrease | B.2.4 |
| **Spatial variance of frequency variation of magnetic susceptibility** | No effect | Strong decrease if the frequency variation of magnetic susceptibility is high enough to affect the detector | B.2.4 |
| **Effective electrical conductivity** | Little effect except for highly conducting soils | Little effect except for highly conducting soils | B.5 |
| **Frequency variation of effective electrical conductivity** | No effect | Decrease | B.5 |
| **Spatial variance of effective electrical conductivity** | Strong decrease if the effective electrical conductivity is high enough to affect the detector | Strong decrease if the effective electrical conductivity is high enough to affect the detector | B.2.4 |
| **Spatial variance of frequency variation of effective electrical conductivity** | No effect | Strong decrease if the frequency variation of effective electrical conductivity is high enough to affect the detector | B.2.4 |
| **Surface roughness variation** | Strong effect if the effective electrical conductivity or magnetic susceptibility affects the detector | Strong effect if the effective electrical conductivity or magnetic susceptibility affect the detector | B.9 |
| **Ground reference height** | Strong decrease | Strong decrease | 5.4 |
| **Spatial variance of ground reference height** | Strong decrease for small ground reference height | Strong decrease for small ground reference height | B.2.4 |
| NOTE 1 If a continuous wave metal detector uses more than one frequency, refer to the column for pulsed induction metal detectors since the frequency variation of soil properties might affect its performance. | | | |
| NOTE 2 Relevant frequencies for electromagnetic properties mentioned in the table are those in the metal detector frequency range. | | | |

## 6.5 Relative soil comparison rules for ground penetrating radars

The following rules describe qualitatively how some soil properties influence the performance of ground penetrating radars. This is expected to be more useful to select soils to build test lanes.

**Table 8 — Global rules on ground penetrating radar performance**

| When the value of this soil property increase… | Ground penetrating radar performance tends to… | |
|---|---|---|
| Attenuation coefficient | …decrease. | See B.6 |
| Characteristic impedance contrast between the mine and the soil | … increase. | See B.7 |
| Characteristic impedance contrast between the air and the soil | … decrease. | See B.7 |
| Electric object size in soil | … increase. | See B.8 |
| Surface roughness | … decrease. | See B.9 |
| Spatial variance of soil properties | … decrease. | See B.2.4[a] |
| a B.2.4 uses a sampling distance of 100 cm. Variations at this scale can make the air-soil interface response vary and hence influence the capability of the ground penetrating radar to cancel this response. Variations at a smaller scale may also influence GPR performance but there is currently no established method to measure them. | | |

NOTE 1 Vegetation of the surface can have an effect on ground penetrating radar performance partly because it changes electromagnetic properties but also because it can affect the sweep height.

NOTE 2 Roots, rocks, cracks and other voids in soil may increase the number of false alarms.

# Annex A
# (Informative)
# Effects of soils on metal detectors and ground penetrating radars

## A.1 General

### A.1.1 Introduction

The performance of metal detectors and ground penetrating radars may depend on the electromagnetic properties of the soil and how these properties vary from one location to the other. A soil may reduce the sensitivity of a detector and generate false alarm indications.

At any given location, soil electromagnetic properties depend on a wide range of factors, including local geology, topography and climate and variation in soil mineralogy, chemistry, texture, moisture content and temperature.

### A.1.2 Description of soil electromagnetic properties

The electromagnetic response of a given soil is described by three intrinsic parameters: electrical conductivity, electric permittivity (both known collectively as the electrical parameters) and magnetic susceptibility.

In general, foregoing material parameters are dispersive, meaning that their values and relative influence depend on frequency.

The combined influence of electrical parameters is such that in practice measuring instrument measure related frequency-dependent composite parameters referred to as:

- the effective electrical conductivity,
- the effective electric permittivity, and
- the magnetic susceptibility.

In contrast with electrical properties, which are predominantly controlled by water content, clay content and clay mineralogy, soil magnetic susceptibility is not influenced by water content but is largely dependent on mineralogy and temperature. Both electrical and magnetic properties are substantially influenced by soil texture whereas frequency dependence of magnetic susceptibility is influenced by grain-size distribution in the range of nanometres. Soil properties can vary with space and time. Smaller-scale soil variability is a source of clutter, reducing signal to noise ratio and related performance. Consequently, effective characterisation requires that related measurements of adequate samples be done. Adequate sampling is required to characterize the nature and extent of smaller-scale variability due to localized heterogeneity, including cobbles, boulders and anomalous water content levels.

It must also be recognized that soil electromagnetic properties and their variability are not the only factors limiting the practical performance of a given detector. For instance, radar scattering due to surface relief and overlying vegetation is very significant for ground penetrating radar performance.

Finally, it is emphasized that the ability to predict sensor performance on the basis of soil measurements is limited because of the complexity of the phenomenon.

### A.1.3 Difference between metal detectors and ground penetrating radars

At the outset, it is essential to appreciate that the nominal operating frequency of conventional metal detectors is several orders of magnitude lower than that of ground penetrating radars incorporated in dual-sensor systems. For this reason, related soil influence on the two detectors is considerably different. In fact, the very way in which the transmitted signal propagates into the soil is fundamentally different for metal detectors and ground penetrating radars. In essence, it is the complementary nature of these two contrasting modes of electromagnetic sensing that is exploited by dual sensor technologies.

Metal detectors are predominantly influenced by the soil magnetic susceptibility (and its frequency variation) and ground penetrating radars are predominantly influenced by electrical conductivity and electric permittivity. All are influenced by soil inhomogeneity.

## A.2 Effects of soils on metal detectors

Some soil can significantly affect metal detector performances. The effect of a soil on a metal detector can be defined as one of the following:

**Table A.1 — Definition of classes for soil effects on metal detectors**

| | |
|---|---|
| **Neutral** | A soil has a **neutral** effect on a metal detector if it has a no effect on the performance of the metal detector even without ground compensation. For the detector, such a soil is equivalent to air. |
| **Moderate** | A soil has a **moderate** effect on a metal detector if its effect on the detector performance is noticeable but the metal detector can be used without ground compensation. |
| **Severe** | A soil has a **severe** effect on a metal detector if it makes the use of ground compensation necessary. |
| **Very severe** | A soil has a **very severe** effect on a metal detector if the metal detector cannot be used even with ground compensation. |

**Magnetic susceptibility** is the soil property that has the most important effect on metal detectors. Effective electrical conductivity can also have an impact on metal detector performance but it is expected to be quite rare and limited to certain wet areas that are influenced by salt water, such as near beaches and areas flooded by salt water during high tides.

NOTE The problem does not come from salt alone but from salt in combination with water. Fertilizer and livestock urine have also been reported to increase electrical conductivity.

EXAMPLE The inclusion of salt water is one of the main reasons why a soil can have high effective electrical conductivity. For sand, effective electrical conductivity can vary from 0,001 $Sm^{-1}$ when it is dry to 0,2 $Sm^{-1}$ when it is saturated with salt water, which means a multiplication by a factor of 200.

Both the low frequency value and the frequency variation of the magnetic susceptibility and effective electrical conductivity may affect detector performance. The dominant effect depends on the detector technology. Metal detectors can be divided into two groups: the continuous wave (also known as frequency-domain) metal detectors and the pulsed induction (also known as time-domain) metal detectors. Soil low-frequency electromagnetic properties influence them in different ways. In particular, for continuous wave metal detectors operating at a single frequency, it is simply the magnitudes of electromagnetic properties at the particular operating frequency that influence the performance. In contrast, for pulsed induction metal detectors, which effectively operate over a broad range of frequencies, both the magnitudes and frequency dependence of soil electromagnetic properties have influence on performance. Continuous wave metal detectors operating at several frequencies are influenced by the electromagnetic properties at these frequencies. The resulting influence may make these detectors behave more like pulsed induction metal detectors than single-frequency continuous wave metal detectors.

These soil properties may vary from point to point and, as a result of this spatial variation combined with the fact that the surface of the soil is not normally flat (surface roughness), the response from the soil will also vary from point to point.

The variation of the response caused by the soil may have a significant impact on detector performances. Therefore, considering an average value of the magnetic susceptibility and effective electrical conductivity will only give a rough first estimate of detector performances. To assess detector performances fully, spatial variation of magnetic susceptibility as well as surface roughness should also be considered over the whole area. If some decrease of performance cannot be explained by magnetic susceptibility, then effective electrical conductivity could be investigated.

The variation of soil response, due to soil roughness and inhomogeneity, only needs to be considered if the soil response is measurable.

## A.3 Effects of soils on ground penetrating radars

A ground penetrating radar is an instrument that contains a transmitting antenna and a receiving antenna, which allow it to send and detect electromagnetic waves at given frequencies, and is designed to detect electromagnetic contrasts in the soil. In mine clearance operations the transmitting antenna sends a wave that propagates into the soil. Whenever the wave encounters a variation of electromagnetic properties, part of it is reflected back to the surface (reflected wave) and the rest continues to propagate into the ground (transmitted wave). When a wave reaches a mine and is reflected, it is this reflected wave that is detected by the receiving antenna of the ground penetrating radar.

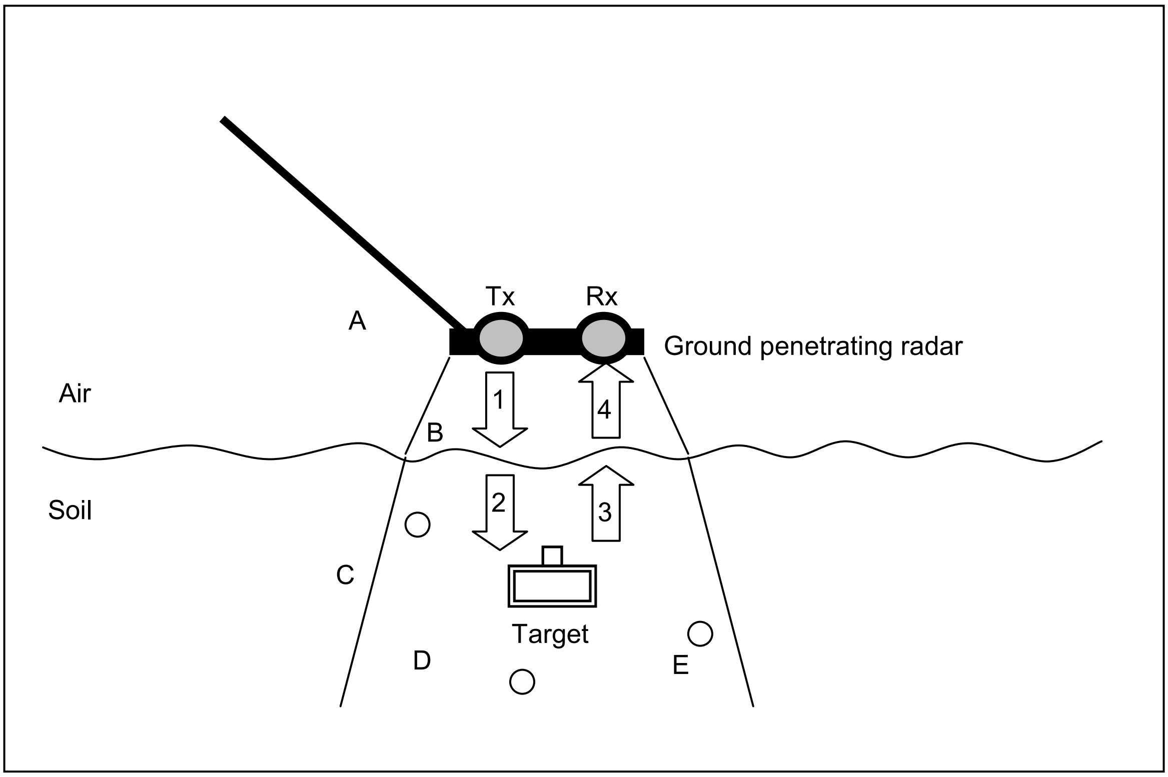


**Figure A.1 — Basic principles of a ground penetrating radar: numbers represent how the wave propagates; letters represent sources of losses; see text for details.**

NOTE 1 This is a simplified explanation of how a ground penetrating radar works. In practice more complex behaviours can occur.

A soil can have many effects on a ground penetrating radar ability to detect a mine. First, it reflects a large part of the wave at the soil surface. Second, if soil electromagnetic properties are close to those of a mine the wave may have reduced reflection when it reaches the mine and the detection might be difficult. Third, the soil can attenuate the wave. All these effects essentially reduce the strength of the transmitted wave and the reflected return signal, making detection difficult. Since attenuation increases with depth, it may limit the depths at which a mine can be detected. The presence of small electromagnetic inhomogenieties, such as stones or holes, can also create clutter in the radar signal.

These phenomena are described in **Error! Reference source not found.**:

— The radar transmitting antenna (Tx) sends a wave to the ground (1) that first reaches the soil surface. Since air and soil have very different electromagnetic properties a part of the wave is reflected back to the ground penetrating radar and a part goes through the ground (2). How much of the wave is reflected back depends on the electromagnetic properties of the soil, the surface roughness and the frequency of the wave. The reflection of the radar wave at the air-soil interface depends on the angle of incidence and the air and soil characteristic impedances. The characteristic impedance of a medium is a property that can be estimated from its basic electromagnetic properties: its effective relative electric permittivity, its effective electrical conductivity and its magnetic permeability. The larger the impedance contrast between air and soil, the higher the reflection coefficient, and the larger the reflection. A large reflection between air and soil is an obstacle to detection.

NOTE 2 In practice soil magnetic permeability can generally be neglected because it affects ground penetrating radar performance far less than soil effective relative electric permittivity and soil effective electrical conductivity. If the ground penetrating radar is used properly the influence of the incidence angle can also be neglected.

— When reaching a mine, part of the wave is reflected. The proportion of the wave that is reflected depends mainly on the reflection coefficient between soil and mine and the geometric properties of the mine. Detection is easier if the reflection between soil and mine is large i.e. if soil and mine characteristic impedances are very different.

— The reflected wave then travels back through the soil (3).

— Finally the surface is reached and part of the wave propagates through the air to reach the receiving antenna (Rx) of the radar (4).

Best detection is achieved when the signal that is reflected at the mine and reaches the receiving antenna is as strong as possible. Therefore losses undergone by the wave from the transmitting antenna to the mine and back to the receiving antenna hamper detection.

**Error! Reference source not found.** also describes possible sources of losses:

A) If the operator lifts the sensor head over the ground the radar wave is sent to a wider area on the surface and therefore the wave energy per unit surface is reduced. This loss is sometimes called spreading loss or spherical attenuation. A proper use of the ground penetrating radar should limit this loss.

B) When the soil surface is not flat the reflection of the wave changes. This surface roughness has an effect on the part of the wave transmitted through the surface. Additionally surface roughness can add spatial variations in the signal which create clutter and may reduce the ground penetrating radar performance.

C) The energy of the wave is not emitted equally in all directions but is concentrated inside a beam. When the beam enters the soil it is refracted and becomes narrower because of the difference of electromagnetic properties between air and soil. The wave energy per unit surface is then increased, which may lead to a better detection and a smaller footprint. **Error! Reference source not found.** provides a simplified illustration of this phenomenon.

D) When a wave propagates in a soil that exhibits some effective electrical conductivity, it is gradually attenuated. The deeper the mine, the greater this effect. When present the attenuation is also a function of the soil effective relative electric permittivity. There is no such attenuation in air because air has no effective electrical conductivity.

E) The presence of localised areas with electromagnetic properties different from the surrounding soil such as stones, roots, rocks, or cracks, can create as many reflections. This has two effects: it can create responses that can be misinterpreted as mines, and it reduces amplitude of the wave reaching the target, hence reducing mine detectability.

The response from a landmine received at the receiving antenna depends therefore on the following properties:

— the characteristic impedance of the soil,

— the attenuation of the soil,

— the electromagnetic properties of the landmine (characteristic impedance), and

— the geometric properties of the landmine, which affects the reflection of the radar wave in a very complex manner.

Soil electromagnetic properties can vary with time particularly in response to prevailing weather conditions. Since effective relative electric permittivity depends mainly on soil water content it can increase after a rain and decrease as the soil dries out. This change over time depends on the soil texture. For instance clay can retain more water and for a longer time than sand.

The effects of impedance contrast and attenuation due to soil can oppose each other. For instance when the soil is wet its effective relative electric permittivity is high, which will make the detection of mine easier but may also reduce the detection depth. Depending on the dominant effect, detection may be easier or more difficult.

# Annex B
# (Normative)
# How to determine soil properties

## B.1 General

This annex describes how to determine the soil properties that are cited in 6. Some are physical or electromagnetic properties that can be measured with the appropriate equipment. Others can be computed or derived from physical and electromagnetic properties.

## B.2 General measuring procedures

### B.2.1 Principle

General procedures to measure soil properties are described. To measure an average value of a soil property that can vary in space, the procedure in B.2.2 shall be used. To take samples of soil for an analysis in a laboratory, the procedure in B.2.3 shall be used. To describe the spatial variability of a soil property the procedure in B.2.4 shall be used.

To carry out soil sampling or measurements in an area that is not accessible it is necessary to choose samples from a part of the terrain that is similar (i.e. similar terrain or slope position, similar soil colour on the surface, similar texture, similar stone content and similar amount of rock outcrops, similar land use and vegetation).

NOTE When there is a slope; soil properties tend to vary more in the direction of the slope.

Soil properties should be measured at least down to the maximum depth at which test objects are buried in the test site. A deeper depth may be required because the soil below a test object can affect a metal detector.

### B.2.2 Procedure to measure average values

#### B.2.2.1 Principle

This procedure shall be used to measure an average value of a soil property that can vary in space.

#### B.2.2.2 Equipment

The measuring instrument dedicated to the soil property to measure shall be used.

#### B.2.2.3 Procedure

The following procedure shall be followed.

a) Select an area of at most 5 $m^2$ with the same soil colour, texture and stone content.

b) Choose nine sampling locations.

c) Take nine measurements according to the pattern shown in Figure B.1.

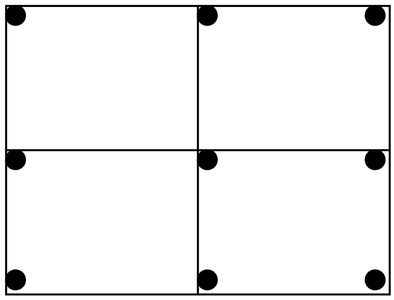

Figure B.1 — Grid for soil sampling

#### B.2.2.4 Reporting

The average of the nine measurements shall be recorded.

### B.2.3 Sampling procedure for laboratory measurement

#### B.2.3.1 Principle

This procedure shall be used to sample soils before an analysis in a laboratory.

Soil properties can vary abruptly with depth because soils are formed of layers. These layers shall be sampled separately.

Figure B.2 illustrates a typical soil profile with a frequently appearing combination of layers and depths of layers. It should be noted that individual layers, such as the organic layer and the topsoil, could be absent. Therefore, a soil profile can be shorter and single layers may be proportionally larger.

NOTE In this context layers are also called horizons.

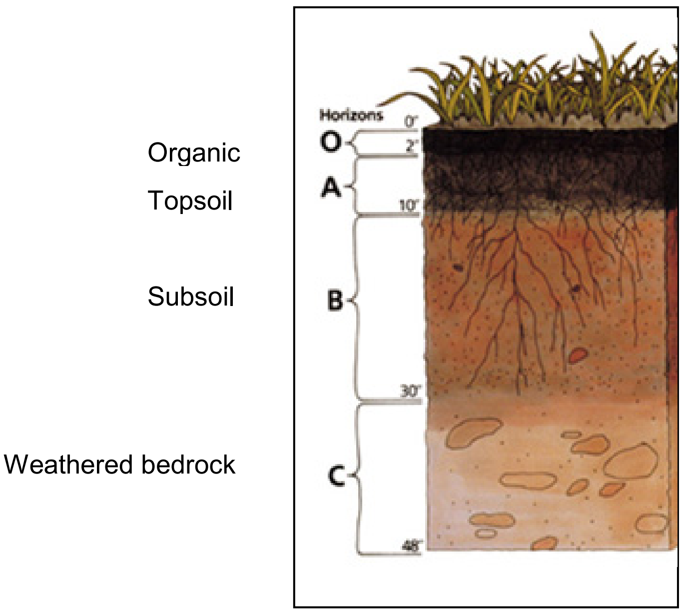


**Figure B.2 — A typical soil profile with an organic layer (O-horizon), a topsoil (A-horizon), a subsoil (B-horizon) and weathered bedrock (C-horizon), (From [23])**

The layers are commonly distinguished by recognising changes in colour and/or texture with depth. Some soils feature an organic surface layer, which usually appears on woodland or grassland soils and which is mostly thinner than 10 cm. This layer can be recognised by its dark grey or black colour and the absence, or a very low amount, of mineral soil particles.

The topsoil, which underlies the organic layer, consists predominantly of the sand, silt and clay sized mineral particles of the soil. The topsoil is characterised by a certain humus content, which can be recognised by its grey colour. In the absence of an organic layer the topsoil forms the soil surface. The depth of the topsoil depends on many natural factors and the agricultural use, and is often between 5 cm and 30 cm.

The subsoil beneath the topsoil is characterised by lower humus content or even the complete absence of organic material. It has often a brown, red, yellow or light grey colour.

#### B.2.3.2 Equipment

For the measurements of some soil properties it is acceptable to take disturbed samples that can be taken with a small shovel or a knife.

EXAMPLE It is acceptable to use disturbed samples to measure magnetic susceptibility.

If physical properties have to be determined with undisturbed samples, special equipment, e.g. a manual core sampler, shall be used.

EXAMPLE Determining effective relative electric permittivity requires undisturbed samples.

#### B.2.3.3 Procedure

The following procedure shall be followed.

a) Select an area of at most 5 $m^2$ with the same soil colour, texture and stone content.

b) Choose nine sampling locations.

c) Remove plants and plant remnants from the chosen locations.

d) Take nine apple-sized samples from each layer (the organic layer, when present, the topsoil and the subsoil) according to the pattern shown in Figure B.1.

   1) Remove the organic layer, when present, so that the material cannot be mixed with the underlying mineral layers and sample it separately.

   2) If there is a second layer within 40 cm from terrain surface, sample the topsoil from its top (the lower boundary of the organic layer) to its lower boundary but not deeper than 40 cm below the ground surface.

   3) Sample the subsoil layer from its top up to a depth of approximately 40 cm from terrain surface.

e) If the soil contains rocks or rock fragments sample these components separately. Overall a sample weight of approximately 500 g should be chosen.

f) Mix the nine samples of each layer to make a composite sample and put it in a plastic bag or glass jar with screw caps which shall be labelled with the name of the site, the depth of sampling and the name of the layer. When possible, add the coordinates of the sample place.

The samples are then ready for storage and delivery to a laboratory.

#### B.2.3.4 Reporting

Values for the soil property to be measured shall be recorded by depth or layer.

### B.2.4 Procedure to estimate spatial variability of soil properties

#### B.2.4.1 Principle

This procedure shall be used to investigate the spatial variability of soil properties in the terrain by measuring these properties at different locations.

NOTE This procedure uses a sampling distance of 10 cm. Variations at this scale can make the air-soil interface response vary and hence influence the capability of a detector to cancel this response. Variations at a smaller scale may influence performance of ground penetrating radars but there is currently no established method to measure them.

#### B.2.4.2 Procedure

A location where the soil type does not change significantly shall be chosen. If there are visual clues of a considerable change of soil properties, such as the change of soil colour, soil texture, stone content or vegetation inside the area to be explored, the procedure should be followed for each soil type and measurements carried out for each individual soil type.

An area 10 m x 10 m shall be selected. The spacing between two measuring points should be in the range of approximately 10 cm and comply with the measuring volume of the instrument used to measure the soil property. The soil property should be measured along at least two 10 m lines that intersect perpendicularly within the area.

Figure B.3 is the grid recommended for more sophisticated analysis.

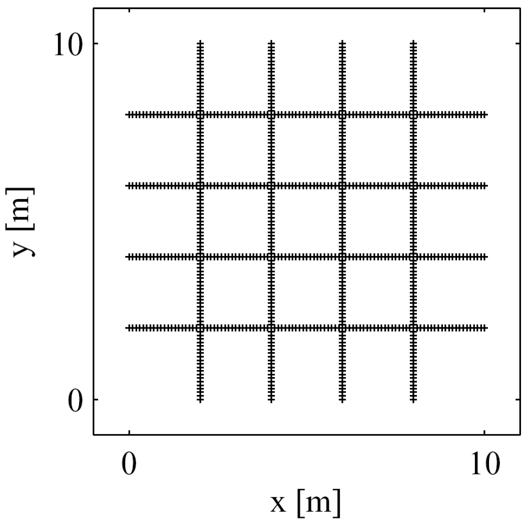


**Figure B.3 — Measuring grid recommended for thorough determination of spatial variability of physical soil properties on the scale of a few metres. Sampling distance in the profiles is 10 cm. (From [15])**

#### B.2.4.3 Reporting

Spatial variability of a soil property shall be recorded by the variance of the measurements, as defined by:

$$V = \frac{1}{N-1}\sum_{i=1}^{N}\left(m_i - \overline{m}\right)^2 \quad \text{with} \quad \overline{m} = \frac{1}{N}\sum_{i=1}^{N} m_i$$

where

$V$ is the spatial variability expressed by the variance

$N$ is the number of measurements

$m_i$ is the i$^{th}$ measurement

For more complete reporting the variability should be expressed also in terms of the correlation length of measurements. If the distance between two locations is larger than the correlation length their soil properties are likely to be independent from each other.

Readings of the physical soil property can also be plotted in a 2D-graph to illustrate how soil properties vary with space. This will specify the most likely value of a physical property in an area and how strong this property can vary. A geo-statistical analysis by means of variogram calculation can be used to describe the spatial pattern and how fast the property is expected to vary inside the field [18].

## B.3 Magnetic susceptibility

### B.3.1 Principle

The magnetic susceptibility of a soil and its frequency variation strongly affect the performance of metal detectors. In this section, the procedure to measure these properties is described.

### B.3.2 Equipment

Magnetic susceptibility and its frequency variation can be measured by an electromagnetic induction-measuring instrument.

In order to obtain a measurement that reflects the same volume of soil as the metal detector to be used the measuring instrument should have a coil size similar to the detector to be used.

The measuring instrument should measure the magnetic susceptibility at two frequencies — in the frequency band used by metal detectors — that are sufficiently different. The higher frequency should be at least ten times as large as the lower frequency.

### B.3.3 Procedure

The measuring instrument should be calibrated as described in the user manual before use.

The procedure in the user manual of the measurement instrument shall be followed.

If possible magnetic susceptibility should be measured at least at two frequencies.

For laboratory measurements disturbed samples can be used.

### B.3.4 Reporting

Volume magnetic susceptibility shall be reported. The mass and volume of the sample shall be reported too.

Magnetic susceptibility and its frequency-variation should be expressed in SI units.

If the higher frequency used by the measuring instrument is ten times as large as the lower frequency, then the frequency variation is computed by the difference between the two measured susceptibility values. This measurement is also known as frequency-dependent susceptibility.

Otherwise the following equation shall be used:

$$d\kappa = -\frac{\kappa_2 - \kappa_1}{\log_{10}\left(\frac{f_2}{f_1}\right)}$$

where

$d\kappa$ is the frequency variation of the magnetic susceptibility

$f_1$ is the lower frequency used by the measuring instrument

$f_2$ is the higher frequency used by the measuring instrument

$\kappa_1$ is the (volume) magnetic susceptibility value measured at frequency $f_1$

$\kappa_2$ is the (volume) magnetic susceptibility value measured at frequency $f_2$

NOTE $\log_{10}$ represents the logarithm in base 10.

The make and model of the measuring instrument shall be recorded, as there may be significant differences between measuring instruments, such as the volume of soil interrogated, the fields or the frequencies used.

## B.4 Effective relative electric permittivity

### B.4.1 Principle

The effective relative electric permittivity of a soil strongly affects the performance of ground penetrating radars. In this section, the procedure to measure it is described.

### B.4.2 Equipment

A time-domain reflectometer (TDR) can be used.

NOTE TDR is an easy-to-use and widely used tool for these measurements [6][19]. It has, however, some limitations. Other methods have been proposed [1][16].

### B.4.3 Procedure

The procedure in the user manual of the measurement instrument shall be followed. Since effective relative electric permittivity may vary with time, it shall be measured regularly and at least every day at the beginning and end of any test.

The soil should not be wetted because it would modify the electric permittivity.

For laboratory measurements undisturbed samples shall be taken.

### B.4.4 Reporting

Effective relative electric permittivity shall be expressed in SI units.

The make and model of the measuring instrument shall be recorded.

## B.5 Effective electrical conductivity

### B.5.1 Principle

The effective electrical conductivity of a soil affects the performance of ground penetrating radars and, to a lesser extent, metal detectors.

The variation of the effective electrical conductivity with frequency should also be considered. Therefore the effective electrical conductivity should be measured at two or more frequencies in the frequency band used by the detector.

The spatial variation of the effective electrical conductivity should also be considered because it can also have a significant impact on the performance of metal detectors. This variation can be obtained following the procedure described in B.2.4.

NOTE As insufficient experimental data is available, no absolute classification of the soil effects (neutral, moderate, severe, very severe), based on soil effective electrical conductivity has been attempted in this document.

### B.5.2 Equipment

Effective electrical conductivity can be measured by a time-domain reflectometer (TDR) or a meter with contact probes or in the laboratory using a coaxial line at a frequency range close to the working frequency of the detector.

NOTE As an alternative to contacting quadrupole electrode measurements, electromagnetic induction instruments can be employed for field assessment. However, these instruments require relatively precise calibration and are subject to considerable thermal drift.

The instrument should be calibrated as described in the user manual before use.

### B.5.3 Procedure

Effective electrical conductivity should be measured in-situ.

The procedure in the user manual of the measurement instrument shall be followed.

Since effective electrical conductivity may vary with time, it shall be measured regularly and at least every day at the beginning and end of any test.

If possible effective electrical conductivity at two frequencies should be measured.

### B.5.4 Reporting

Effective electrical conductivity shall be expressed in siemens per metre $Sm^{-1}$.

Make and model of the measuring instrument shall be recorded, as there may be significant differences between the instruments such as the volume of soil interrogated or the frequencies used.

## B.6 Attenuation coefficient

The attenuation coefficient affects the performance of ground penetrating radars. It shall be computed with the following equation:

$$\alpha = 2\pi f \sqrt{\frac{\mu\varepsilon_0\varepsilon_S}{2}\left(\sqrt{1+\left(\frac{\sigma}{2\pi f\varepsilon_0\varepsilon_S}\right)^2}-1\right)}$$

where

- $\alpha$ is the attenuation coefficient, expressed in neper per metre ($Npm^{-1}$).
- $\varepsilon_0$ is the absolute permittivity of vacuum, its value is 8,85 $10^{-12}$ $Fm^{-1}$
- $\varepsilon_S$ is the effective relative electric permittivity of the soil, use the value measured as described in B.4
- $\sigma$ is the effective electrical conductivity of the soil; use the value measured as described in B.5
- $f$ is the frequency at which the soil properties have been measured
- $\mu$ is the effective magnetic permeability of the soil; the value of $4.\pi.10^{-7}Hm^{-1}$, which is the value of vacuum, can be used.

NOTE When the absolute permittivity of vacuum expressed in $Fm^{-1}$, the effective relative electric permittivity of the soil in SI units, the effective electrical conductivity of the soil in $Sm^{-1}$, the frequency in Hz and the effective magnetic permeability of the soil in $Hm^{-1}$, the above equation provide the value of the attenuation coefficient expressed in $Npm^{-1}$.

The attenuation coefficient should be expressed in neper per metre ($Npm^{-1}$). It could also be expressed in decibel per meter ($dBm^{-1}$). The value of the attenuation coefficient expressed in $dBm^{-1}$ is related to the value expressed in $Npm^{-1}$ by:

$$\alpha_B = 8{,}686\,\alpha_N$$

where

$\alpha_B$ is the numerical value of the attenuation coefficient, expressed in decibel per metre ($dBm^{-1}$)

$\alpha_N$ is the numerical value of the attenuation coefficient, expressed in neper per metre ($Npm^{-1}$)

EXAMPLE Figure B.4 shows how the attenuation coefficient varies with effective relative electric permittivity and effective electrical conductivity for two frequencies: 500 MHz and 1 GHz.

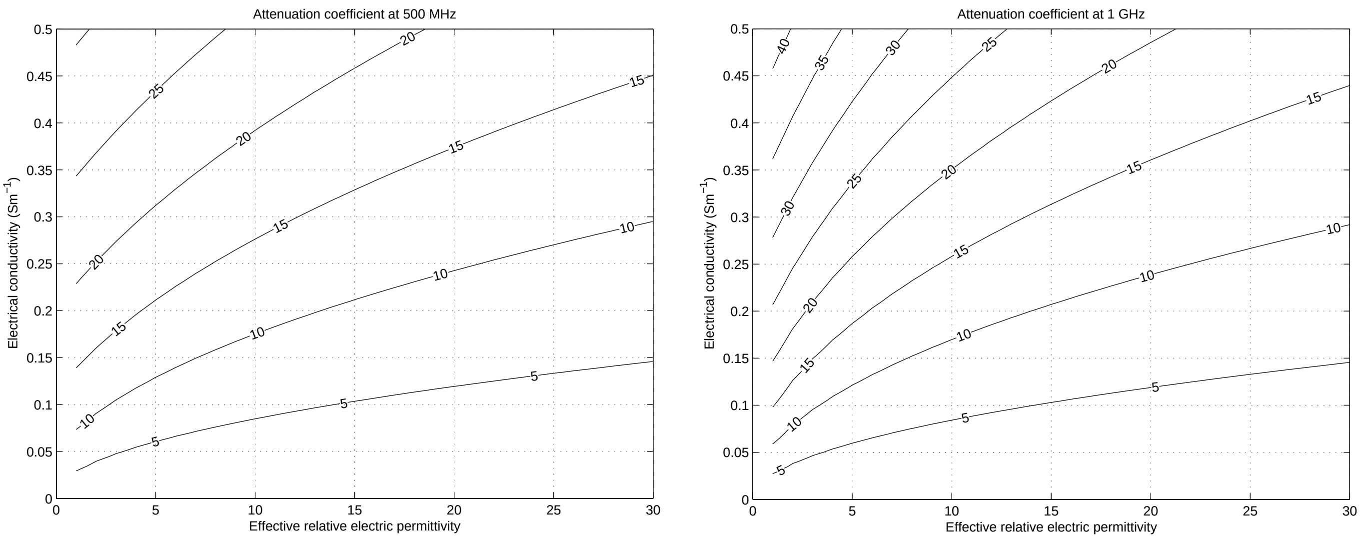


**Figure B.4 — Attenuation coefficient as a function of effective relative electric permittivity and effective electrical conductivity at 500 MHz (left) and 1 GHz (right). The values of the attenuation coefficient (expressed in $Npm^{-1}$) are given on the curves.**

## B.7 Characteristic impedance of soil

The soil characteristic impedance affects ground penetrating radars and is computed with the following equation:

$$|Z_s| = \left|\sqrt{\frac{\mu}{\varepsilon_0 \varepsilon_S}}\left(1+\tan\delta_E{}^2\right)^{-\frac{1}{4}}\right| \text{ with } \tan\delta_E = \frac{\sigma}{2\pi f \varepsilon_S}$$

where

$\mu$ is the magnetic permeability of the soil; a value of $4.\pi.10^{-7}Hm^{-1}$ can be used.

$\varepsilon_0$ is the permittivity of vacuum, its value is 8,85 $10^{-12}$ $Fm^{-1}$

$\varepsilon_S$ is the effective relative electric permittivity of the soil, use the value measured as described in B.4

$\sigma$ is the effective electrical conductivity of the soil; use the value measured as described in B.5

*f* is the frequency at which the soil properties have been measured

Characteristic impedance shall be expressed in Ohm (Ω).

NOTE The characteristic impedance of soil can be compared to the impedance of air that can be estimated by $\sqrt{\frac{\mu_0}{\varepsilon_0}}$, which is approximately 377 Ω. It can also be compared to an estimate of the characteristic impedance of a mine. The characteristic impedance of a mine can be estimated by using the equation for the characteristic impedance of soil above with $\tan \delta_E = 0{,}001$ and by replacing $\varepsilon_S$ by $\varepsilon_T = 2{,}5$, which is typical for explosive. This gives a value of approximately 238 Ω. To compare the characteristic impedances of two media (soil and air or soil and target) , the reflection coefficient can be used. It is approximated by:

$$R = \frac{|Z_2| - |Z_1|}{|Z_2| + |Z_1|}$$

where

$|Z_1|$ is the characteristic impedance of the first medium, expressed in Ohm (Ω)

$|Z_2|$ is the characteristic impedance of the second medium, expressed in Ohm (Ω)

## B.8 Electric object size

The electric object size in soil is important for ground penetrating radar performance and can be estimated by:

$$S = Df\sqrt{\mu\varepsilon_0\varepsilon_s}$$

where

- *D* is a characteristic dimension of the object, expressed in metre (m)
- *f* is the frequency of the GPR
- *μ* is the effective magnetic permeability of the soil; a value of $4.\pi.10^{-7}$ $Nm^{-1}$ can be used
- $\varepsilon_0$ is the permittivity of vacuum, its value is 8,85 $10^{-12}$ $Fm^{-1}$
- $\varepsilon_s$ is the effective relative electric permittivity of the soil, use the value measured as described in B.4.

The characteristic dimension chosen for the object shall be recorded.

## B.9 Surface roughness

### B.9.1 Principle

Surface roughness is a measurement of the small-scale variations in the profile of the soil surface. If a soil presents some difficulties to a detector, a greater surface roughness can increase difficulties for the detector. In general surface roughness affects ground penetrating radar performance more than metal detector performance.

The use of a laser range finder is recommended for high accuracy.

An optional technique is described below.

NOTE Surface roughness can also be known as surface microtopography.

### B.9.2 Equipment

The procedure requires a needle profiler.

A needle profiler consists of a wooden plate with a 1 m long aluminium rod fixed at its base. Two poles and a spirit level are used to maintain the profiler horizontally. Upon the rod, there are holes through which aluminium needles slide. The distance between the holes depends on the (maximal) frequency of the ground penetrating radar:

$$d = \frac{c}{10f} = \frac{\lambda}{10}$$

where

d is the numerical value of the distance between the holes, expressed in metre (m)

f is the numerical value of the (highest) frequency of the ground penetrating radar, expressed in Hertz (Hz)

λ is the numerical value of the (smallest) wavelength of the ground penetrating radar, expressed in metre (m)

**Figure B.5 — Needle profiler**

See Figure B.6 and Figure B.7.

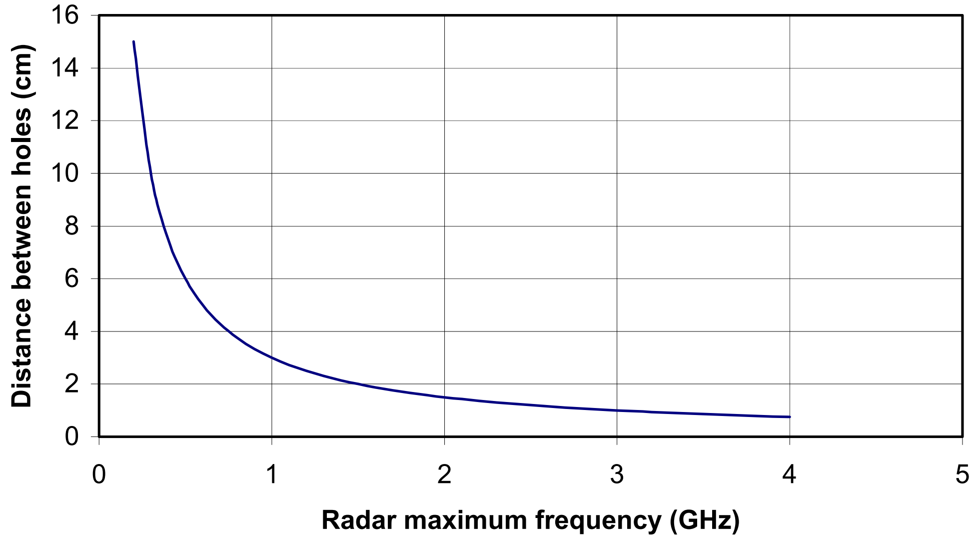


**Figure B.6 — Distance between holes with respect to GPR maximal frequency**

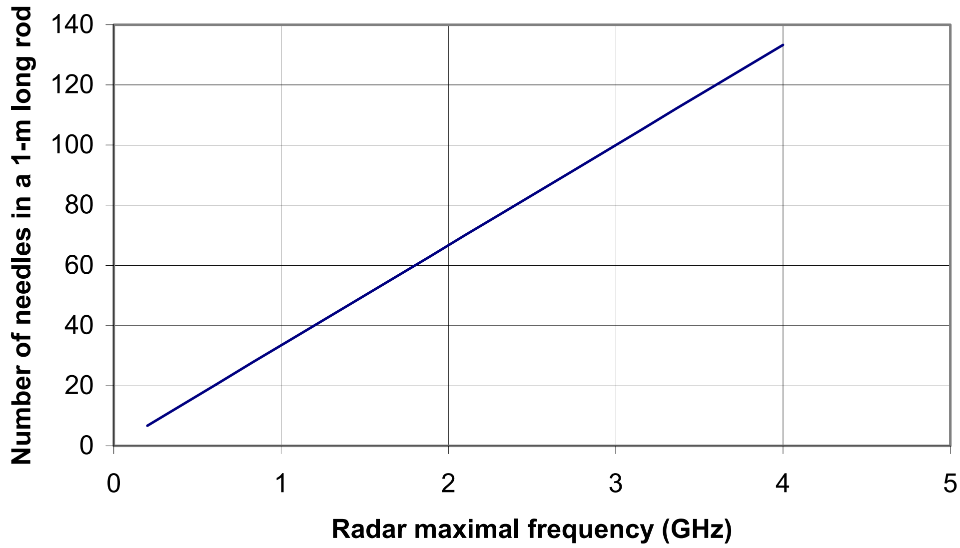


**Figure B.7 — Number of needles in a 1-m long rod with respect to GPR maximal frequency**

EXAMPLE If the ground penetrating radar operates in the frequency band 1 GHz to 3 GHz. The maximal frequency is $f = 3 \times 10^9$ Hz and therefore, the distance between holes is $d = 3 \times 10^7 / 3 \times 10^9 = 0{,}01$ m. Then, the number of needles (holes) to place in a 1 m long rod at a distance of 1 cm is 101.

## B.9.3 Procedure

When the profiler is mounted:

a) Select a 1 m wide area with little or no vegetation.

b) Place the profiler (with the needles) on the ground. The upper tips of the needles will delineate the profile of the soil situated below the plate. Note that if the soil surface is friable (dusty, very dry) or very wet, the bottom tips of the needles could penetrate the soil surface. If this occurs, mention it on the record sheet.

c) Place a string at the same level of the maximum upper tip.

d) Place a second string at the same level of the minimum upper tip.

e) Place the third string at the half distance between the maximum and minimum string. This string indicates the zero level.

Using the ruler, record all the positions of the upper tips of the needles relatively to the zero level. Those that are above the zero level are positive values and those that are below are negative.

### B.9.4 Reporting

Surface roughness shall be recorded by:

$$\sigma^2 = \frac{1}{N-1}\sum_{i=1}^{N}\left(x_i - \bar{x}\right)^2 \text{, with } \bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \ .$$

Where

σ is the root mean square, characterising the surface roughness, expressed in metre (m)

*N* is the number of needles

$x_i$ is the position of the upper tip of the i$^{th}$ needle, expressed in metre (m)

The curve of the position $x_i$ can also be provided.

## B.10 Soil water content

### B.10.1 Principle

Soil water content is the factor that has the greatest influence on a soil effective relative electric permittivity. Since soil water content may vary with time, it shall be measured regularly and at least every day at the beginning and end of any test. In general soil water content affects the performance of ground penetrating radars and metal detectors in specific cases, such as saline soils.

NOTE Soil water content is also called soil moisture.

### B.10.2 Measuring soil water content in field

- **Recommended method**: Capacitance/Time-domain reflectometer (TDR) probe

Soil water content can be measured directly in the field using a direct-reading capacitance or time-domain reflectometer (TDR). The TDR probe should be used according to manufacturer recommended procedures.

- **Optional method**: without instruments

This method can be used to characterise locally the soil water content at various depths.

a) Collect a soil sample of the size of a ball of approximately 4 cm in diameter from the surface layer.

b) Perform the simple tests listed in Table B.1.

**Table B.1 — Classification of water content status of soil (source: [9], table 57)**

| | Actions | | | |
|---|---|---|---|---|
| | **Crush** | **Form (to a ball)** | **Moisten after adding one spoonful of water** | **Water content class** |
| **Results** | Dusty or hard | Not possible, seems to be warm | Going very dark | Very dry |
| | Makes no dust | Not possible, seems to be warm | Going dark | Dry |
| | Makes no dust | Possible (not sand) | Going slightly dark | Slightly moist |
| | Is sticky | Finger moist and cool, weakly shiny | No change of colour | Moist |
| | Free water | Drops of water | No change of colour | Wet |
| | Free water | Drops of water without crushing | No change of colour | Very wet |
| NOTE This is a very rough method which gives an estimation of water tension; a specific water tension is related to different water contents in different soil textures. | | | | |

This procedure should be repeated for samples taken from the subsurface (10–15 cm depth), from the same square metre and at the same locations (or nearby) as where the surface sample was taken.

NOTE This optional gives very rough results and should be carried out by experienced people.

### B.10.3 Estimating soil water content inhomogeneity

Soil water content shall be measured in a one square metre area by a capacitance/Time-domain reflectometer (TDR) probe.

Differences between the measurements of soil water content of several samples provides characterisation of the horizontal water content variability and the vertical water content variability These are important parameters as a very inhomogeneous soil (horizontally, vertically or in both directions) could produce related detector responses that could be interpreted as alarm indications.

**Horizontal soil water content variability at the surface** shall be estimated by computing the difference between the highest and the lowest soil water content measured at surface.

**Horizontal soil water content variability at the subsurface** can be estimated by computing the difference between the highest and the lowest soil water content measured at the same subsurface depth.

**Vertical soil water content variability** can be estimated by the following procedure:

a) Dig a 50 cm deep pit

b) Measure soil water content at surface and subsurface with the TDR probe

c) Compute the absolute value of the difference between soil water content status at surface and subsurface.

NOTE The vertical soil water content variability is expected to be relatively constant from one location to the next. Therefore estimating it at one location is enough.

Soil water content spatial variability shall be measured according to B.2.4.

### B.10.4 Measuring soil water content in laboratory

#### B.10.4.1 General

Water content can be assessed in the laboratory by drying samples and determining relative mass of liberated soil water [22]. Both gravimetric and volumetric soil water content shall be reported.

**Special equipment**:

- Soil samples,
- Oven working at 105°C (or microwave oven),
- Balance (0,1 g precision),
- Oven-safe containers.

For disturbed or undisturbed soil sampling:

- Cylindrical tubes with lids, also called core cutter,
- Flat-bladed or filling knife,
- Hermetic plastic bags,
- Marker pen.

Soil water content can be measured in laboratory by

a) Taking a undisturbed sample of soil in the field,

b) Measuring as-sampled soil mass

c) Drying the sample at 105°C until mass stops decreasing (see below),

d) Measuring dry soil mass to yield, and

e) Estimate the soil water content (see below).

For this measurement, a balance of 0,1-g precision is needed.

If no special oven working at 105°C is available, a microwave oven can be used for **drying**:

i) Measure as-sampled soil mass,

ii) Place the soil sample in the microwave and dry with four-minute cycles at full power until mass stops decreasing. Open the microwave door for one minute between cycles to allow venting.

iii) Measure dry soil mass,

iv) Record the weight, and the difference between the dry-soil mass and the as-sampled soil mass as estimate of the water mass.

v) Estimate of soil water content (see below).

**B.10.4.2 Gravimetric soil water content**

Soil gravimetric water content is then calculated as:

$$\theta_g = \frac{m_{wet} - m_{dry}}{m_{dry}}$$

where

$\theta_g$ is the gravimetric soil water content

$m_{dry}$ is the mass of the oven-dried soil

$m_{wet}$ is the mass of the moist soil

This procedure should be repeated for different soil samples (taken at different depths and locations).

#### B.10.4.3 Volumetric soil water content

Volumetric soil water content is measured from an undisturbed sample obtained by a manual core sampler.

It shall be estimated by:

$$\theta_v = \theta_g \frac{\rho_b}{\rho_w}$$

where

$\theta_v$ is the volumetric soil water content

$\theta_g$ is the gravimetric soil water content, estimated as described in B.10.4.2

$\rho_b$ is the bulk soil density

$\rho_w$ is the temperature-specific density of water

NOTE The volume of water can be computed from the water mass of the undisturbed sample or from the disturbed sample when the bulk soil density is known.

## B.11 Documenting weather conditions

**Special equipment**: none (Optional: thermometer).

The weather conditions during the tests as well as the days or weeks before the tests influence soil water content. Hence these should be noted. In addition, the prevailing general weather conditions and the air temperature at the time of tests as well as that of the near past should be documented (see Table B.2).

**Table B.2 — Codes for weather conditions**

| **Present weather conditions** |
|---|
| Sunny/clear |
| Partly cloudy |
| Overcast |
| Rain |
| Sleet |
| Snow |
| **Former weather conditions** |
| No rain in the last month |
| No rain in the last week |
| No rain in the last 24 hours |
| Rainy without heavy rain in the last 24 hours |
| Heavier rain for some days or rainstorm in the last 24 hours |
| Extremely rainy time or snow melting |

## B.12 Soil texture

### B.12.1 General

Soil texture is defined by the percentage of clay, silt and sand in soil. Soils dominated by clay-sized grains may higher effective electrical conductivity than soils with greater proportions of silt or sand. They also tend to retain more water, which affects the effective relative electric permittivity.

More generally, characterisation of soil texture should also account for coarser materials, including gravel and cobbles that are potentially an important source of interference and soil noise in connection with mine detection.

### B.12.2 Estimating soil texture in field

The texture can be estimated in the field by feeling (or ‘qualitatively assessing’) the constituents of the soil. For this, the soil sample (size: 4 cm of diameter) must be in the state moist or wet as defined in Table B.1. Gravel and other constituents with diameter larger than 2 mm must be removed (by hand).

The constituents have the following feel:

- **Clay**: soils are cohesive (sticky), formable, have a high plasticity and have a shiny surface after squeezing between fingers.
- **Silt**: soils are non-sticky, only weakly formable, have a rough and ripped surface after squeezing between fingers and feels very floury (like talcum powder)
- **Sand**: cannot be formed, and feels very grainy.

Table B.3 describes a method to estimate the percentage of clay and characterise the soil.

**Table B.3 — Classification of soil texture**

| | Test | Class | Percentage of clay |
|---|---|---|---|
| **1** | **Not possible to roll a string of about 7 mm in diameter (about the diameter of a pencil)** | | |
| 1.1 | Not dirty, not floury, no fine material in the finger rills…………………………… | Sand | Below 5 |
| 1.2 | Not floury, grainy, scarcely fine material in the finger rills, weakly shapeable, adheres slightly to the fingers…………………………………………………… | Loamy sand | Below 12 |
| 1.3 | Similar to 1.2 but moderately floury…………………………………………….. | Sandy loam (clay-poor) | Below 10 |
| **2** | **Possible to roll a string of about 3 mm to 7 mm in diameter but breaks when trying to form the string to a ring of about 2 cm to 3 cm in diameter, moderately cohesive, adheres to the fingers** | | |
| 2.1 | Very floury and not cohesive and: | | |
| | Some grains to feel……………………………………………………………….. | Silt loam (clay-poor) | Below 10 |
| | No grains to feel………………………………………………………………… | Silt | Below 12 |
| 2.2 | Moderately cohesive, adheres to the fingers, has a rough and ripped surface after squeezing between fingers and: | | |
| | Very grainy and not sticky………………………………………………………... | Sandy loam (clay-rich) | 10 to 25 |
| | Moderate sand grains…………………………………………………………….. | Loam | 8 to 27 |
| | Not grainy but distinctly floury and somewhat sticky…………………………….. | Silt loam (clay-rich) | 10 to 27 |
| 2.3 | Rough and moderate shiny surface after squeezing between fingers and sticky and grainy to very grainy………………………………………………….. | Sandy clay loam | 20 to 35 |
| **3** | **Possible to roll a string of about 3 mm in diameter** | | |
| 3.1 | Very grainy……………………………………………………………………… | Sandy clay | 35 to 55 |
| 3.2 | Some grains to see and to feel, gnashes between teeth and: | | |
| | Moderate plasticity, moderately shiny surfaces………………………………….. | Clay loam | 25 to 40 |
| | High plasticity, shiny surfaces…………………………………………………… | Clay | 40 to 60 |
| 3.3 | No grains to see and to feel, does not gnash between teeth and: | | |
| | Low plasticity…………………………………………………………………… | Silty clay loam | 25 to 40 |
| | High plasticity, moderately shiny surfaces……………………………………….. | Silty clay | 40 to 60 |
| | High plasticity, shiny surfaces…………………………………………………… | Heavy clay | Above 60 |

### B.12.3 Estimating soil texture in laboratory

Soil texture is related to particle sizes. Laboratory methods can be used to measure the particle size distributions [22].

**Special equipment**: access to a specialized laboratory

Particle sizes can be measured in specialized laboratory by sedimentation, sieving or micrometry. Soil particles are grouped according to their size into clay (below 0,002 mm), silt (0,002 mm to 0,63 mm) and sand (0,63 mm to 2 mm). Results of soil gradation are expressed in percentages (%) of clay, silt and sand. Soil texture can be classified according to the soil texture triangle of Figure B.8.

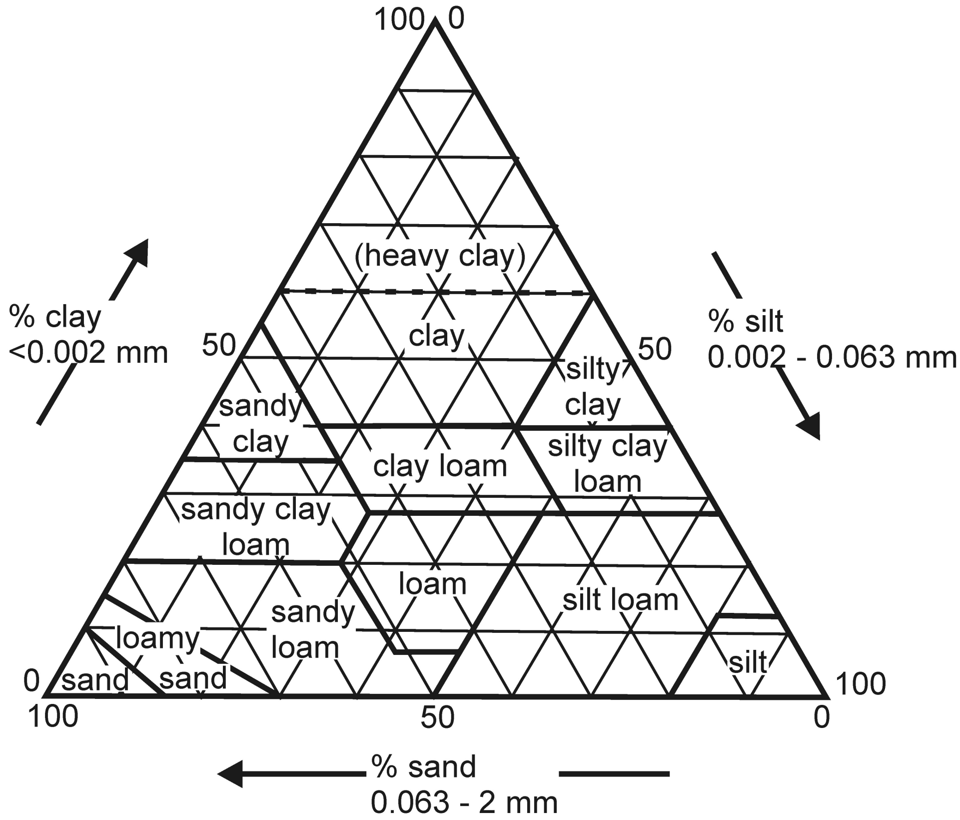


**Figure B.8 — Soil textural triangle (Source: adapted from [24])**

EXAMPLE A soil containing 20% of clay, 30% of silt and 50% of sand is loam as seen in Figure B.9.

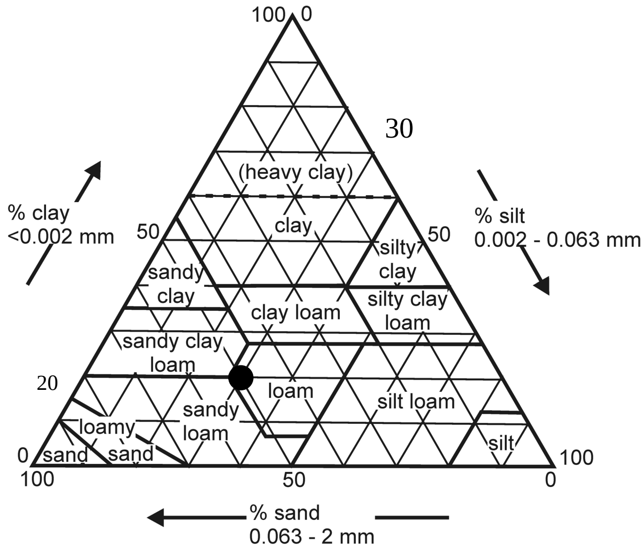


**Figure B.9 — Example of use if the soil textural triangle with 20% clay, 30% silt and 50% sand**

NOTE More accurate measurements of soil particle size distributions (percentage of clay. silt, sand) can be measured in the laboratory. The clay mineralogy can be identified by X-ray diffraction in the laboratory. Cation exchange capacity can be assessed in the laboratory using standardised techniques [22]. These methods are not recommended because they are usually expensive and time consuming.

## B.13 Describing vegetation

**Special equipment**: none.

Vegetation is an important factor in ground penetrating radar performance as it could scatter the radar signal and/or generate false alarms. A code is proposed in Table B.4 to describe vegetation. In accordance with mine clearance Standard Operating Procedures, bushes and grass may have to be cut. When applicable, this information should be mentioned, and, if possible, description before and after vegetation removal should be recorded.

**Table B.4 — List of codes for vegetation**

| Code for vegetation |
|---|
| Tall trees |
| Medium trees |
| Short trees |
| Tall bushes |
| Medium bushes |
| Short bushes |
| Tall grass (above 15 cm) |
| Medium grass (5 cm to 15 cm) |
| Short grass (below 5 cm) |

In addition, other information about vegetation, such as vegetation density (see Table B.5) should be recorded.

**Table B.5 — Classification of vegetation density (surface covered by vegetation)**

| Surface covered by vegetation % | Class of vegetation density |
|---|---|
| 0 | None |
| 0 to 5 | Few |
| 5 to 15 | Common |
| 15 to 40 | Many |
| Above 40 | Abundant |

## B.14 Describing roots

**Special equipment**: none.

Recording both the size and the abundance of the roots is important if trees or bushes are identified in vegetation and their densities have been classified as many or abundant. Classification is listed in Table B.6.

**Table B.6 — Classification of the diameter of roots**

| **Diameter of roots** cm | **Name** |
|---|---|
| Below 0,5 | Very fine |
| 0.5 to 2,0 | Fine |
| 2,0 to 5,0 | Medium |
| Above 5,0 | Coarse |

The abundance of roots is important if medium or coarse roots are identified. It can be compared within the same size class and it can be expressed in the number of roots per square metre. It can be done by digging at least four holes of 10 cm to 15 cm of depth in an area of 1 square metre.

**Table B.7 — Classification of the abundance of roots**

| **Number of roots per square metre…** | | |
|---|---|---|
| **…if root diameter is between 2 and 5 cm:** | **…if root diameter is above 5 cm:** | **Classification of the abundance of roots** |
| 1 to 5 | 1 to 2 | Few |
| 5 to 20 | 2 to 5 | Common |
| Above 20 | Above 5 | Many |

## B.15 Describing rocks

**Special equipment**: none.

Classification is listed in Table B.8.

**Table B.8 — Classification of rock fragments**

| **Greatest dimension** cm | **Name** |
|---|---|
| 0,2 to 0,6 | Fine gravel |
| 0,6 to 2,0 | Medium gravel |
| 2,0 to 6,0 | Coarse gravel |
| Above 6,0 | Stone |

The percentage of surface covered by rock fragments is important if coarse gravel or stones are identified. By visual inspection of the surface, the percentage of surface covered can be recorded (see Table B.9). However, additional information about the abundance of stones in the subsurface can be recorded by digging at least 4 holes of 10 cm to 15 cm of depth in an area of 1 square metre.

**Table B.9 — Surface covered by rock fragments**

| **Surface covered by rock fragments** % | **Name** |
|---|---|
| 0 to 5 | Few |
| 5 to 15 | Common |
| 15 to 40 | Many |
| Above 40 | Abundant |

## B.16 Assessing surface cracks

**Special equipment**: none.

Surface cracks can generate non-uniform wetting and preferential flow, thus they can contribute to soil water content variability (see B.10.3). Additionally, wide and deep cracks could produce a different ground penetrating radar response that could be interpreted as alarm indication. They can be estimated by visual inspection. Variation on the width, distance and depth of surface cracks can be classified following the values listed in Table B.10, Table B.11 and Table B.12.

**Table B.10 — Classification of surface cracks 1: width**

| **Width** cm | **Class** |
|---|---|
| Below 1 | Fine |
| 1 to 2 | Medium |
| 2 to 5 | Wide |
| Above 5 | Very wide |

**Table B.11 — Classification of surface cracks 2: distance between cracks**

| **Distance between cracks** cm | **Class** |
|---|---|
| Below 2 | Very closely spaced |
| 2 to 5 | Closely spaced |
| 5 to 20 | Moderately widely spaced |
| Above 20 | Widely spaced |

**Table B.12 — Classification of surface cracks 3: depth**

| **Depth** cm | **Class** |
|---|---|
| Below 2 | Surface |
| 2 to 5 | Medium |
| 5 to 20 | Deep |
| Above 20 | Very deep |

# Annex C
(Normative)
# Writing reports: Description of soils

## C.1 General

When reporting about soil measurements, the procedure shall be described as precisely as possible. Measurement instruments shall be described and their working frequencies noted.

In addition to the information listed in Annex B the following forms can be used when describing soils and related information in test reports.

## C.2 Site identification

| | |
|---|---|
| **Site name:** | |
| **Site location:** | |
| **Coordinates** | |
| **Date:** | |
| **Observer name:** | |

## C.3 General description

| | | |
|---|---|---|
| **Site landform type:** | Valley | |
| | Rolling hills | |
| | Steep slopes | |
| | Mountain | |
| | Plateau | |
| | Low land | |
| | Other (please state) | |

| | | |
|---|---|---|
| **Slope:** | Flat (0-2%) | |
| | Sloping (2-20%) | |
| | Steep (Above 20 %) | |

| | | |
|---|---|---|
| **Vegetation:** | Forest | |
| | Woodland | |
| | Shrub | |
| | Short shrub | |
| | Grassland | |
| | Bare ground | |
| | Is ground or vegetation wet? Y/N | |
| | Other (please state) | |

## C.4 Surface conditions

| | | | |
|---|---|---|---|
| **Soil colour:** | Black | | |
| | Grey | | |
| | Dark brown | | |
| | Brown | | |
| | Light brown | | |
| | Yellow | | |
| | Light yellow | | |
| | Red | | |
| | Other (please state) | | |

| | | |
|---|---|---|
| **Surface form:** | Flat | |
| | Flat with surface crust | |
| | Rough | |
| | Mounded | |

## C.5 Sub-surface conditions

| | | | |
|---|---|---|---|
| **Soil colour:** | Black | | |
| | Grey | | |
| | Dark brown | | |
| | Brown | | |
| | Light brown | | |
| | Yellow | | |
| | Light yellow | | |
| | Red | | |
| | Other (please state) | | |

## C.6 Pictures

| | | |
|---|---|---|
| **Pictures taken?** | Site | |
| | Surface | |
| | Soil pit or profile | |

Pictures should include:

- A picture of the general landscape
- A picture of a 1 $m^2$-area, with an object indicating the scale, taken at sunlight, and
- A picture taken after digging, with an object indicating the scale, taken in sunlight.
- A picture of a soil sample against a white background with an object indicating the scale

EXAMPLE Scales, rulers, pens, etc. can be used to indicate the scale of a picture.

## C.7 Other observations

| | |
|---|---|
| **Other observations** | |
| **Site map or sketch?** | |

# Annex D
(Normative)
**Measuring the effects of soils on a given metal detector**

## D.1 General

Three tests are described:

- Comparing false alarm rate and probability of detection between the soil of interest and a neutral soil, in D.4
- Comparing false alarm rate only between the soil of interest and a neutral soil, in D.5
- Estimating the detection depth and its variance, in D.6

In most cases, the test in D.6 may be performed with the true test target in-air above the soil. This significantly simplifies the test, as the true test targets need not be buried. This requires a number of assumptions to be valid. These assumptions are first described in D.2 and D.3, as well as their expected validity limits and procedures to check their validity.

If the assumptions are not valid, the test in D.6 may still be performed but the true test targets must be buried.

These tests shall be used if the soil has non-deterministic effects on detection. Otherwise tests in 5.2 shall be used.

## D.2 Symmetry assumption

### D.2.1 Motivation

The symmetry assumption must be valid if one wants to simplify test D.6 by putting the true test target in-air above the soil. This significantly simplifies the test, as the true test targets need not be buried. If the assumption is not valid, the test may still be performed but the true test targets must be buried.

### D.2.2 Definition

The symmetry assumption means that the coil plane is a plane of symmetry for the magnetic field. When this is the case, the response of a mine below the detector is identical to the response of a mirror mine above the detector as indicated in Figure D.1.

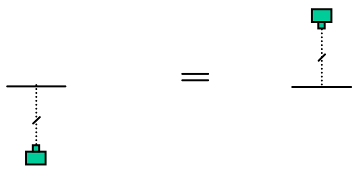

**Figure D.1 — Symmetry assumption**

NOTE Practically, a mirror mine is in general not available and the original mine, flipped upside-down, will be used instead. This should not make any difference because the detectability of the mirror and upside-down mines should be identical.

### D.2.3 Symmetry assumption validity

At a few centimetres, the details of the coil winding become irrelevant and the coil produces the same field as a single-turn planar coil. When this is the case, and if the material used to build the detector head is non-magnetic and non-conducting, one can show that the symmetry assumption is valid, using the relation between the current and the magnetic field. Therefore, the assumption is expected to be valid for all metal detectors. For dual-sensors, ground penetrating radar antennas are built with metal and this may distort the resulting metal detector magnetic field. If the distortion is significant, the symmetry assumption shall not be used.

### D.2.4 Symmetry assumption test

In case of doubt, the procedure described here can be used to check the assumption. Note that the symmetry assumption is never used alone. It is only useful if the decoupling assumption is also valid. The procedure described in D.3 tests both assumptions together. Therefore, the procedure to test the symmetry assumption should only be used if one is confident that the decoupling assumption is valid but one has doubts about the symmetry assumption.

The in-air test defined in CWA 14747-1, 6.4.2 shall be performed with the true test target below the surface and flipped upside-down above the detector head. Other metals or specific true test targets (see CWA 14747-1, 6.5.3 and 6.6) may be used as well but ideally the obtained detection distances should cover the distances of interest for test in D.6.

If the symmetry assumption is valid, the difference between the two curves should be compatible with experimental errors. The error shall be estimated as explained in CWA 14747-1, 6.3.3.

## D.3 Decoupling assumption

### D.3.1 Motivation

The decoupling assumption must be valid if one wants to simplify test D.6 by putting the true test target in-air above the soil. This significantly simplifies the test, as the true test targets need not be buried. If the assumption is not valid, the test may still be performed but the true test targets must be buried.

### D.3.2 Definition

If soil effective electrical conductivity and magnetic susceptibility are low enough, the soil and true test target responses decouple. As illustrated in Figure D.2, this means that the total response is the sum of:

- the response of the true test target in air and
- the response of the soil in absence of true test target.

NOTE The response considered is the voltage induced in the reception coil. For the processed response or the audio response, the total response is not necessarily the sum of the individual contributions because the processing may be non-linear (non linear first amplifier, non-linear audio coding, etc.)

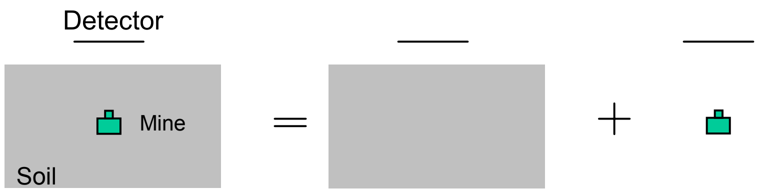


**Figure D.2 — Decoupling assumption**

When the symmetry assumption and the decoupling assumptions are valid, tests can be made with the true test target in air, which allows the test procedure to be significantly sped up because the true test target does not need to be buried in the soil. This is illustrated in Figure D.3.

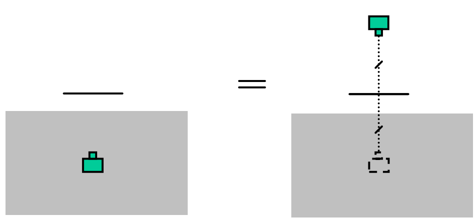

**Figure D.3 — Decoupling and symmetry**

### D.3.3 Decoupling assumption validity

Theoretical results [8], [7] suggest that for most soils, the magnetic susceptibility and the effective electrical conductivity should be low enough to make the decoupling assumption valid. Note that the decoupling assumption is always used together with the symmetry assumption. Therefore, if the symmetry assumption is not valid, it makes no sense to check the validity of the decoupling assumption.

NOTE The decoupling assumption might not be valid for soils with very high magnetic susceptibility or effective electrical conductivity. But these cases are expected to be rare.

In case of doubt the tests described here allows to tests both the decoupling and symmetry assumptions together.

### D.3.4 Motivation

The symmetry and decoupling assumption test allows testing the validity of the symmetry and decoupling assumption together. It is however more time consuming than the test described in D.2.4. Therefore, if the decoupling assumption is known to be valid and the user only wants to check the symmetry assumption, test D.2.4 shall be preferred.

### D.3.5 True test targets

The test shall be performed with the true test targets used in the test in D.6. If the test is limited to a subset of the true test targets used in D.6, the subset shall include the true test targets for which the assumption is the most likely to be wrong. Real (inert) mines or mine-like true test targets, as described in CWA 14747-1, 5.6, 3) and 5), should be preferred to true test targets that are significantly smaller than real mines (such as parametric true test targets).

### D.3.6 Test area preparation

The vegetation shall be cut short to allow sweeping as specified below, and the area should be free from unintentional metal fragments.

NOTE 1 The objective is to check if the response of the true test target in air above the soil is the same as the response of the true test target in the soil. Therefore, measurements will first be performed with the true test target in-air and the true test target will then be buried. Ideally, only the soil volume replaced by the true test target should be removed and no other soil volume should be disturbed. A small displacement of a metallic object yielding a significant detector response is a significant disturbance and should therefore be avoided. The easiest way to reach this objective is to remove the unintentional metal fragments.

NOTE 2 It is expected that the above requirements should not involve additional work because more stringent vegetation clearance and unintentional metal fragment removal are in general required for the test D.6.

### D.3.7 Test procedure

The test is performed in two phases. First, the true test target is put in-air above the soil, then the true test target is buried in the soil and detection distance for both configurations are then compared.

The test shall be repeated at 10 randomly chosen positions in the test area defined for the test D.6. For each position, a test area of 1 m by 1 m shall be marked.

- In-air phase

The maximum height above the true test target at which the true test target is detectable shall be determined. For this, the true test target shall be fixed at increasing height above the middle of the 1 m by 1 m test area and the detector shall be swept 5 cm above the soil. If the soil is not flat, the sweep height shall be 50 mm above the highest point of the test area.

The detector shall be set up and the sweep performed as required in the test D.6, apart for the sweep height above soil that shall be kept at 50 mm. A mechanical system that does not disturb the detector should be used to fix the true test target and to ensure that the detector height above the soil is kept constant.

The criteria defined in CWA 14747-1, 5.5 shall be used to decide whether the true test target is detectable or not.

- In-soil phase

The true test target is buried at the centre of the test area at a depth 50 mm smaller than the maximum height above the true test target determined in the in-air phase. Ideally, only the soil volume replaced by the true test target should be removed and no other soil volume should be disturbed. For this a mechanical device such as a hollow tube should be used to remove the soil and put it back in place over the true test target.

To validate the burial procedure, the soil may be removed and put back in place without actually inserting the true test target. The in-air phase may then be repeated and detection distance compared with first measurement. If the procedure is appropriate, the detection distances obtained for both measurements should be comparable.

The detector shall then be swept above the soil at increasing heights and the maximum height at which the true test target can be detected shall be determined. The criteria defined in CWA 14747-1, 5.5 shall be used to decide whether the true test target is detectable or not. Steps of 1 cm should be used for the detector height and a mechanical system that does not disturb the detector should be used to keep the detector height above the soil constant.

### D.3.8 Test results reporting

If the decoupling and symmetry assumptions are valid, the maximum sweep height at which the true test target is detected should be 5 cm. The experimental errors shall be estimated (error on true test target depth, error on sweep height, etc.). The difference between the maximum detection height and 5 cm should be compatible with experimental errors. If not, the assumption may still be used if the error is within the required accuracy of the test in D.6.

## D.4 Comparing performance with neutral soil

### D.4.1 Motivation

Probability of detection and false alarm rate can be significantly influenced by the soil. A difficult soil can reduce the probability of detection or increase the false alarm rate.

NOTE 1 Using the ground compensation feature can reduce the detector’s normal sensitivity significantly depending on the technical solution found by the manufacturer.

The false alarm rate can be increased because the soil response that can be confused with the response of a target but also because the soil reduces or deforms the response of a non-mine object, rendering a target identification more complex. This second phenomenon can play a significant role for dual sensors but is expected to be largely irrelevant for metal detectors that do not perform any discrimination. Therefore objects representative of metal fragments are not required for comparison with neutral soil.

NOTE 2 The loss in probability of detection is in general more important to measure than the increase in false alarm rate.

NOTE 3 The effect of soil on false alarm rate should only be assessed if the soil produces a significant number of false alarms.

The effect of the soil on the false alarm rate and the probability of detection can be assessed by comparing the results for the soil of interest and for a neutral soil. If no neutral soil is available, the test can be performed above a mechanical assembly making an in-air blind test possible.

The assembly must:

- be built with a neutral material such as wood,
- keep the detector at a height over the ground that ensures that the soil does not influence the detector,
- provide a flat surface above which normal sweeping can be performed,
- allow the true test targets to be hidden, and
- allow the true test targets to be fixed at a desired distance from the upper surface

As the goal of this blind test is to assess the effect of the soil, a limited number of true test targets and depths may be used. To allow comparison between various soils, it is important to use the same set of configurations for all soils. This is realistic only if the number of configurations remains as limited as possible. Using a single true test target is not recommended because soil compensation may affect the true test target response by an amount varying largely from one true test target to another.

### D.4.2 True test targets and burial depth

The chrome steel balls defined in CWA 14747-1, B.1 should be used because they provide a limited set of true test targets with a good diversity of signatures. If not available, other parametric true test targets may be used but this reduces comparability with results obtained by other organizations.

All balls shall be buried at depths ranging from flush to the maximal detection depth by steps of 5 cm. The maximum detection depth shall be determined independently for each ball at a reference location of the test area using the test defined in CWA 14747-1, 6.6.

The diameters of the balls shall be chosen to ensure that the detection depth varies between 5 and 20 cm.

Additionally, other true test targets of interest as described in CWA 14747-1, 5.6 may be used.

### D.4.3 Test procedure

The test lanes shall be prepared and the test shall be performed according to CWA 14747-1, 8.5. The soil used in the test lanes shall be chosen according to CWA 14747-1, 8.5. Additionally a test lane with neutral soil should be used for comparison.

### D.4.4 Test results reporting

The soil effect can be assessed by comparing the probabilities of detection and false alarm rates for the soil of interest and the neutral soil. To assess whether the variation is statistically relevant, the confidence intervals shall be taken into account.

For the false alarm rate, the comparison is straightforward because the false alarm rate is characterized by a single number.

For the probability of detection, the comparison is more complicated because the values obtained for each true test target and depth must be considered. It is therefore advantageous to present the results graphically. Therefore, the probability of detection shall be plotted as function of the ball diameter for each depth.

### D.4.5 Number of cells

The number of test objects for each configuration shall be large enough to ensure that the confidence interval width is smaller than 20 percentage points. The number of test objects required depends on the configuration and the corresponding probability of detection and can be evaluated according to Annex F.

Similarly, the number of cells without test objects shall be large enough to ensure that the confidence interval width of the false alarm rate is smaller than 30% of the false alarm rate. The number of test objects required depends on the false alarm rate and can be evaluated according to Annex F.

As the number of test objects and empty cells required are function of the probability of detection and false alarm rate, which are unknown at the onset, two approaches can be used:

- A conservative number of test objects may be used, or
- A limited number of test objects may be used for a first test to get an estimated value for the probability of detection and false alarm rate and the corresponding required number of test objects. A second test is then performed with the appropriate number of test objects.

## D.5 Comparing performance with neutral soil (limited to false alarm rate)

Although it is mainly important to estimate the loss in probability of detection due to the soil, it may be advantageous to restrict the comparison with neutral soil (see D.4) to the evaluation of the false alarm rate only.

NOTE 1 The effect of soil on false alarm rate should only be assessed if the soil produces a significant number of false alarms.

When this is the case, the test may be simplified by significantly reducing the number of true test target configurations to consider.

At least 5 true test targets shall be buried. Those true test targets will be put at random locations in the test lane. The true test target and its depth shall be chosen so that the detection is possible but not too easy. For this, maximum height above the true test target shall be determining using the procedure described in CWA 14747-1, 8.3.

NOTE 2 In theory, the test could be performed without burying any true test target. The false alarm rate, however, could be underestimated. Indeed if operators are aware of this, they might be tempted to neglect some weak alarm indications which they would have otherwise reported. Furthermore, there is no way to check that the sensitivity has been set appropriately and the detector is indeed working efficiently. In case of such a problem, the false alarm rate obtained would be abnormally low.

As the maximum detection depth may vary from point to point, the test shall be performed at each location where a true test target is to be buried. The true test target shall be buried at a depth equal to 80% of the maximum height above the true test target. A detection test shall then be performed to check that the true test target yields a clear alarm indication.

The test is then performed as described in D.4 apart that only the false alarm rate and its confidence interval shall be computed.

This modified test does not provide any relevant information concerning the probability of detection.

The test shall be rejected if any of the true test targets is missed.

## D.6 Measuring the detection depth

### D.6.1 Motivation

The detection performance of a detector may also be characterized by the detection depth and its variance. This detection depth can be determined experimentally. To assess the variance of the measurement, several sources of variation will be considered.

### D.6.2 True Test targets

The motivation and constraints for true test target selection are identical to the comparison with neutral soil (see D.4.2).

The test may be performed with the true test target buried in the soil or with the true test target put in-air above the soil. The geometry is illustrated on the following figure.

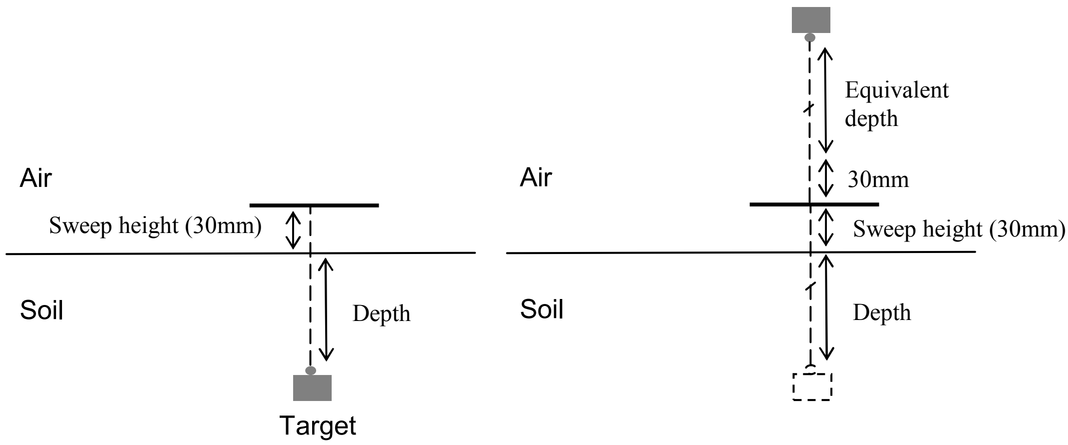


**Figure D.4 — Test geometry: in-soil (left) and in-air (right)**

The ‘in-air true test target’ approach is much more practical but should only be used if the symmetry and decoupling assumptions are valid. Tests D.2 or D.3 shall be performed to determine the validity of the assumptions.

Burying the true test target may disturb the soil and caution must be taken to ensure representative results (waiting long enough between the true test target burying and the measurement). This problem is avoided by leaving the true test target in air.

In all cases, the test is performed on a test cell and the setup is performed on a calibration cell. The way to choose those cells is described in D.6.3.

- True test target buried in soil

The procedure defined in CWA 14747-1, 8.3 shall be used to determine the maximum detection depth. The sweep height is 30 mm.

- True test target in air

The procedure is similar to the in soil case except that the true test target shall not be buried in the soil but shall be fixed in air in the centre of the test cell. The true test target shall be put upside down.

To fix the true test target at various heights above the soil, a mechanical device that does not interact with the detector should be used.

This device should also make it possible to fix the detector height above the soil at 30 mm as required. This ensures that the distance between the detector and the true test target is known and fixed. The equivalent detection depth is the maximum detection distance (distance between detector head and true test target) minus the sweep height (30 mm).

### D.6.3 Test variance

Several factors may influence the result of the test. The most important are the operator, the soil cell over which the test is performed and the soil cell used to perform the setup. In addition, even with a single setup, a single location and a single operator, the result may vary if the test is repeated several times.

Each factor shall be varied independently and the corresponding variance shall be evaluated.

a) Intrinsic variability

For a reference true test target, a reference operator, a reference location and a reference setup, the test shall be repeated 10 times. The average value and variance are computed.

NOTE A reference setup is characterized by a calibration cell and reference detector setting. The setting includes the ground compensation.

b) Operator variability

For a reference true test target, a reference location and a reference setup, the test should be repeated by ten operators. If it is impossible to appropriately train so many operators, fewer operators may be used, repeating the test after a certain time. The average value and variance shall be computed.

c) Calibration cell variability

For a reference true test target, a reference operator and a reference location, the test shall be repeated 10 times with different setups. For each measurement, a new calibration cell shall be chosen randomly and the setup procedure shall be repeated over it. The average value and variance of the detection results are computed.

d) Test cell variability

For a reference true test target, a reference operator and a reference calibration cell, the test shall be repeated at 10 times on different test cells. For each measurement, the test cell shall be chosen randomly. The corresponding average value and variance are computed.

### D.6.4 Test results reporting

The curve presenting the detection depth as function of the ball diameter should be plotted. The variances should also be indicated. The results should be presented for the neutral soil and for the soil of interest in a way that allows easy comparison.

# Annex E
(Normative)
# Measuring the effects of soils on a given dual sensor

## E.1 Motivation

Probability of detection and false alarm rate can be significantly influenced by the soil. A difficult soil can reduce the probability of detection and increase the false alarm rate.

The false alarm rate can be increased because the soil response that can be confused with the response of an object but also because the soil reduces or deforms the response of a non-mine object (such as a metallic fragment), rendering its identification more complex. This second phenomenon can play a significant role for dual sensors.

The main goal of this test is to supplement 5.5 when the detection is not deterministic. This test can also be used to characterise and compare soils with respect to their effects on the detectors. As explained below test objects shall be chosen accordingly.

This test shall be used if the soil has non-deterministic effects on detection. Otherwise tests in 5.5 shall be used.

## E.2 General

The test lanes shall be prepared and the test shall be performed according to CWA 14747-1, 8.5 except for the following points.

## E.3 True test targets

Since no generally accepted true test targets exist for ground penetrating radar, attention should be paid to choose true test targets that have ground penetrating radar and metal detector response representative of real mines. Since the goal of the test is to characterise the soil, an exact match between true test targets and expected threat is not required.

NOTE People interested in comparing results with other soils might want to choose true test targets used in previous measurement campaigns. See http://www.itep.ws.

True test targets shall be buried at depths ranging from flush to the maximal detection depth by steps of 5 cm.

If a given dual sensor makes it possible to use the metal detectors alone then the maximum detection depth shall be determined independently for each true test target at a reference location of the test area using the metal detector and the test defined in CWA 14747-1, 6.6. Otherwise the maximum detection depths should be determined with the dual sensor.

## E.4 False test objects

If the test is to supplement 5.5 when detection is not deterministic, false test objects shall be chosen to be representative of sources of false alarm indications in real situation. Stainless steel nails or screws 25 mm long and 2 mm or 3 mm in diameter can be used.

If the test is used to characterise and compare soils, stainless steel nails or screws 25 mm long and 2 mm or 3 mm in diameter or chrome steel balls defined in CWA 14747:2003, B.1 can be used.

Stainless steel nails or screws 25 mm long and 2 mm or 3 mm in diameter 10-mm diameter chrome steel balls defined in CWA 14747:2003, B.1 can be used.

NOTE The false test objects shall be placed on the surface and 5-cm deep. There shall be approximately as many false test objects as true test targets.

Non-metal false test objects can be used if there are reasons to believe that the dual sensor can generate an alarm indication with them. Voids in soil for instance can be simulated by plastic containers 15 cm to 20 cm long and 6 cm in diameter.

## E.5 Cells without test objects

Some cells shall be kept empty to assess the false alarms coming from the soil itself.

## E.6 Number of test objects

The number of test objects for each configuration shall be large enough to ensure that the confidence interval width is smaller than 20 percentage points. The number of test objects required depends on the configuration and the corresponding probability of detection and can be evaluated according to Annex F.

Similarly, the number of cells without test objects shall be large enough to ensure that the confidence interval width of the false alarm rate is smaller than 30% of the false alarm rate. The number of test objects required depends on the false alarm rate and can be evaluated according to Annex F.

As the number of test objects and empty cells required are function of the probability of detection and false alarm rate, which are unknown at the onset, two approaches can be used:

- A conservative number of test objects may be used, or

- A limited number of test objects may be used for a first test to get an estimated value for the probability of detection and false alarm rate and the corresponding required number of test objects. A second test is then performed with the appropriate number of test objects.

## E.7 Result reporting

A description of the test objects used should be recorded. The number of test objects used for each test object type shall be mentioned as well as the burial configuration (depth, orientation, location).

The following figures will be computed and reported:

- Number of true test targets that have been detected,

- Number of alarm indications on empty cells, and

- Number of false test objects that have been detected (i.e. considered as a threat)

These data will help estimate the following statistics and their confidence intervals:

- Probability of detection,

- False alarm rate on empty cells, and

- False test object rejection probability

# Annex F
# (Informative)
# Model to estimate confidence interval

## F.1 Confidence interval for probability of detection

### F.1.1 Model used

The model, called Clopper-Pearson interval, is described more completely in [20].

The probability of detections is assumed to be binomially distributed.

NOTE Other models have been proposed for estimating this interval. Clopper-Pearson interval is considered to be conservative.

### F.1.2 Underlying assumption

Detection probability is assumed to be independent and constant for each cell.

NOTE This assumption seems reasonable in practice.

### F.1.3 Equation

The lower and upper bounds of the confidence interval for the probability of detection are given by:

$$P_L = \frac{v_1 F(v_1, v_2, \alpha/2)}{v_2 + v_1 F(v_1, v_2, \alpha/2)} \quad \text{with } v_1 = 2x,\ v_2 = 2(n - x + 1)$$

$$P_U = \frac{v_3 F(v_3, v_4, 1-\alpha/2)}{v_4 + v_3 F(v_3, v_4, 1-\alpha/2)} \quad \text{with } v_3 = 2(x+1),\ v_4 = 2(n - x)$$

where

| | |
|---|---|
| $P_L$ | is the lower bound of the confidence interval for the probability of detection |
| $P_U$ | is the upper bound of the confidence interval for the probability of detection |
| $\alpha$ | represent the degree of confidence of the interval |
| $F_{f,g\ \lambda}$ | is the λ-quantile of the F-distribution with *f* and *g* degrees of freedom |
| $n$ | is the number of true test targets used |
| $x$ | is the number of true test targets that have been detected |

If there is no detection (*x=0*) then the following bounds are recommended:

$$P_L = 0$$
$$P_u = 1 - \sqrt[n]{\alpha}$$

If all true test targets are detected *(x=1)* then the following bounds are recommended:

$$P_L = \sqrt[n]{\alpha}$$
$$P_U = 1$$

### F.1.4 Tables

Table F.1 presents numerical values of the 95%-confidence intervals for some values of the numbers of true test targets and percentages of true test targets that have been detected. The bounds of the intervals are rounded to integers values so that the given intervals are the smallest that contain the exact intervals.

**Table F.1 — 95%-confidence interval for the probability of detection**

| | | **Number of true test targets** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **10** | **20** | **30** | **40** | **50** | **60** | **70** | **80** | **90** | **100** |
| **Percentage of true test targets that have been detected** | **0%** | 0 to 26 | 0 to 14 | 0 to 10 | 0 to 8 | 0 to 6 | 0 to 5 | 0 to 5 | 0 to 4 | 0 to 4 | 0 to 3 |
| | **10%** | 0 to 45 | 1 to 32 | 2 to 27 | 2 to 24 | 3 to 22 | 3 to 21 | 4 to 20 | 4 to 19 | 4 to 19 | 4 to 18 |
| | **20%** | 2 to 56 | 5 to 44 | 7 to 39 | 9 to 36 | 10 to 34 | 10 to 33 | 11 to 32 | 11 to 31 | 12 to 30 | 12 to 30 |
| | **30%** | 6 to 66 | 11 to 55 | 14 to 50 | 16 to 47 | 17 to 45 | 18 to 44 | 19 to 43 | 20 to 42 | 20 to 41 | 21 to 40 |
| | **40%** | 12 to 74 | 19 to 64 | 22 to 60 | 24 to 57 | 26 to 55 | 27 to 54 | 28 to 53 | 29 to 52 | 29 to 51 | 30 to 51 |
| | **50%** | 18 to 82 | 27 to 73 | 31 to 69 | 33 to 67 | 35 to 65 | 36 to 64 | 37 to 63 | 38 to 62 | 39 to 61 | 39 to 61 |
| | **60%** | 26 to 88 | 36 to 81 | 40 to 78 | 43 to 76 | 45 to 74 | 46 to 73 | 47 to 72 | 48 to 71 | 49 to 71 | 49 to 70 |
| | **70%** | 34 to 94 | 45 to 89 | 50 to 86 | 53 to 84 | 55 to 83 | 56 to 82 | 57 to 81 | 58 to 80 | 59 to 80 | 60 to 79 |
| | **80%** | 44 to 98 | 56 to 95 | 61 to 93 | 64 to 91 | 66 to 90 | 67 to 90 | 68 to 89 | 69 to 89 | 70 to 88 | 70 to 88 |
| | **90%** | 55 to 100 | 68 to 99 | 73 to 98 | 76 to 98 | 78 to 97 | 79 to 97 | 80 to 96 | 81 to 96 | 81 to 96 | 82 to 96 |
| | **100%** | 74 to 100 | 86 to 100 | 90 to 100 | 92 to 100 | 94 to 100 | 95 to 100 | 95 to 100 | 96 to 100 | 96 to 100 | 97 to 100 |

EXAMPLE If 50 true test targets are used and all of them are detected during the test, then we can say with 95% confidence that the 'true' probability of detection is between 94% and 100%.

NOTE Interpreting these values must take into account that they are rounded. For instance when one true test target is detected out of ten, the exact lower bound of the 95%-confidence interval is close to 0,25%, which has been rounded to 0% in the table. This does not mean that a probability of detection of 0% is compatible with detecting one true test target out of ten. Likewise the table should not be interpreted as saying that a detection of 100% is compatible with detecting only nine true test targets out of ten.

**Table F.2 — Number of true test targets to obtain a 95%-confidence interval width below 20 percentage points**

| **Expected probability of detection** | **10%** | **20%** | **30%** | **40%** | **50%** | **60%** | **70%** | **80%** | **90%** |
|---|---|---|---|---|---|---|---|---|---|
| **Number of true test targets to obtain a 95%-confidence interval width below 20** | 44 | 70 | 89 | 100 | 104 | 100 | 89 | 70 | 44 |

Since the expected probability of detection is often unknown a conservative choice is to choose 97 true test targets in order to obtain a 95%-confidence interval below 20 percentage points.

## F.2 Confidence interval for false alarm rate

### F.2.1 Model used

The model is described more completely in [21].

The model assumes that the number of false alarms in a single experiment follows a Poisson distribution.

### F.2.2 Underlying assumption

The Poisson model assumes that the false alarm rate in any arbitrary small area is constant and independent from the false alarm rate of the other areas.

There are several reasons for which this assumption is not strictly valid amongst which the use of a detection halo, which imposes that in the halo area at maximum one alarm will be taken into account. Similarly it is quite unlikely that operators will indicate two alarms in close proximity. They will merge them assuming that both alarm indications come from the same object.

Nevertheless, the model used is expected to provide realistic confidence intervals.

### F.2.3 Equation

The lower and upper bounds of the confidence interval for the false alarm rate are given by:

$$A_L = \frac{1}{2R}\chi^2_{2k,\alpha/2}$$

$$A_U = \frac{1}{2R}\chi^2_{2(k+1),1-\alpha/2}$$

where

| | |
|---|---|
| $A_L$ | is the lower bound on the confidence interval for the false alarm rate |
| $A_U$ | is the upper bound on the confidence interval for the false alarm rate |
| $k$ | is the number of false alarm that occurred in the region |
| $R$ | is the area of the region where the false alarms have occurred |
| $\alpha$ | represents the degree of confidence of the interval |
| $\chi^2_{l,\lambda}$ | is the λ-quantile of the chi-square distribution with l degrees of freedom |

If there is no alarm in the region, then the lower bound ($A_L$) is set to 0.

### F.2.4 Tables

**Table F.3 — 95%-confidence interval for the false alarm rate**

| | | **Area of the test (m²)** | | | | |
|---|---|---|---|---|---|---|
| | | **10** | **20** | **30** | **40** | **50** |
| **Measured false alarm per square metre** | **0** | 0,0 to 0,4 | 0 to 0,2 | 0 to 0,2 | 0 to 0,1 | 0 to 0,1 |
| | **0,2** | 0,0 to 0,8 | 0 to 0,6 | 0 to 0,5 | 0 to 0,4 | 0 to 0,4 |
| | **0,4** | 0.1 to 1,1 | 0,1 to 0,8 | 0,2 to 0,7 | 0,2 to 0,7 | 0,2 to 0,7 |
| | **0,6** | 0,2 to 1,4 | 0,3 to 1,1 | 0,3 to 1,0 | 0,3 to 0,9 | 0,4 to 0,9 |
| | **0,8** | 0,3 to 1,6 | 0,4 to 1,3 | 0,5 to 1,2 | 0,5 to 1,2 | 0,5 to 1,1 |
| | **1** | 0,4 to 1,9 | 0,6 to 1,6 | 0,6 to 1,5 | 0,7 to 1,4 | 0,7 to 1,4 |
| | **2** | 1,2 to 3,1 | 1,4 to 2,8 | 1,5 to 2,6 | 1,5 to 2,5 | 1,6 to 2,5 |
| | **3** | 2,0 to 4,3 | 2,2 to 3,9 | 2,4 to 3,7 | 2,4 to 3,6 | 2,5 to 3,6 |
| | **4** | 2,8 to 5,5 | 3,1 to 5,0 | 3,3 to 4,8 | 3,4 to 4,7 | 3,4 to 4,6 |
| | **5** | 3,7 to 6,6 | 4,0 to 6,1 | 4,2 to 5,9 | 4,3 to 5,8 | 4,3 to 5,7 |

EXAMPLE In 0,6 false alarm per square metre has been measured in an area of 40 $m^2$ then we can say with a 95% confidence that the ‘true’ false alarm rate is between 0,3 and 0,9 false alarms per square metre.

**Table F.4 — Area of the region to test to obtain a 95%-confidence interval width below 30%**

| **Expected false alarm rate** ($m^{-2}$) | **0,0** | **0,1** | **0,2** | **0,3** | **0,4** | **0,5** |
|---|---|---|---|---|---|---|
| **Area of region to test in order to obtain a 95%-confidence interval width below 30% of the false alarm rate** ($m^2$) | 13 | 24 | 39 | 55 | 71 | 88 |

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